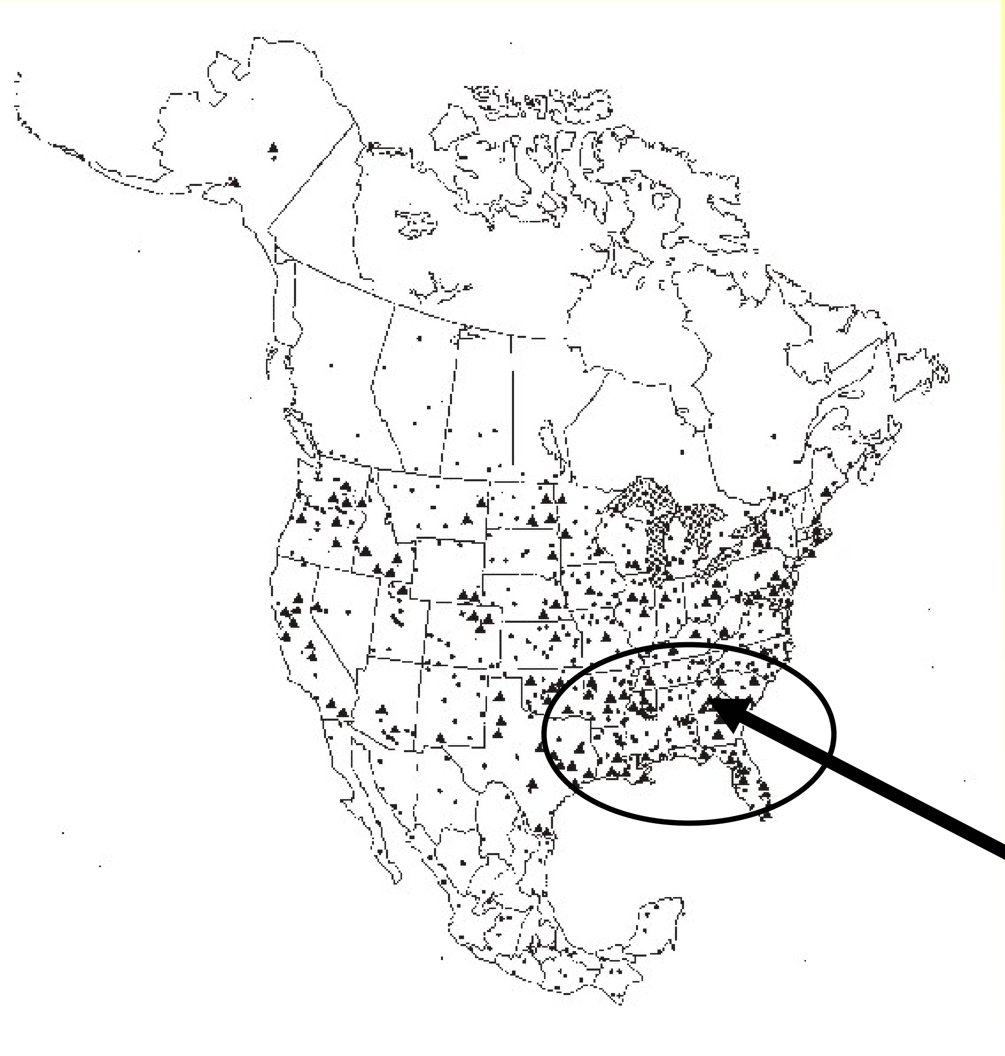
Soil Organic Carbon Sequestration and Nutrient Cycling in Pastures of the Southeastern USA



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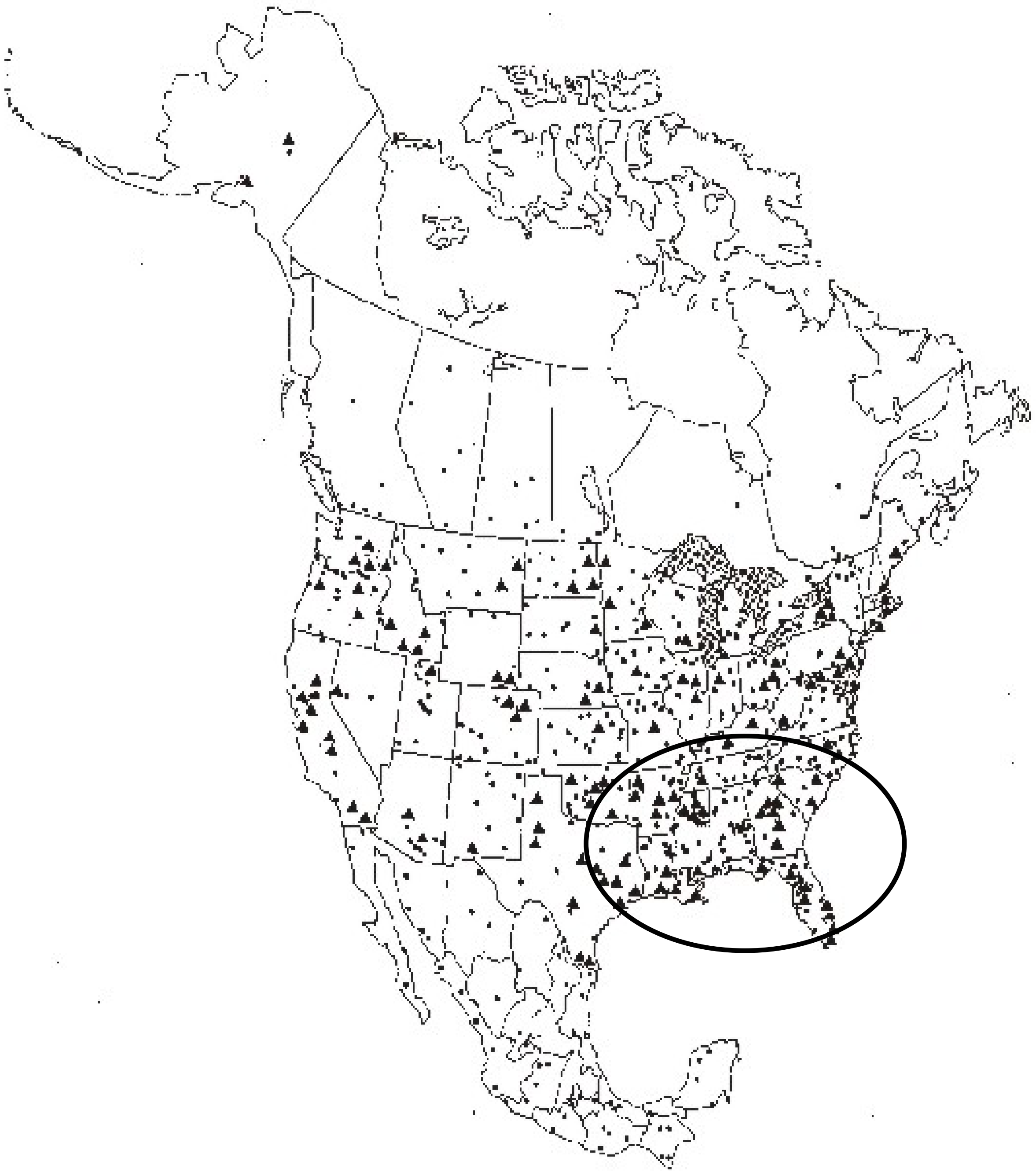
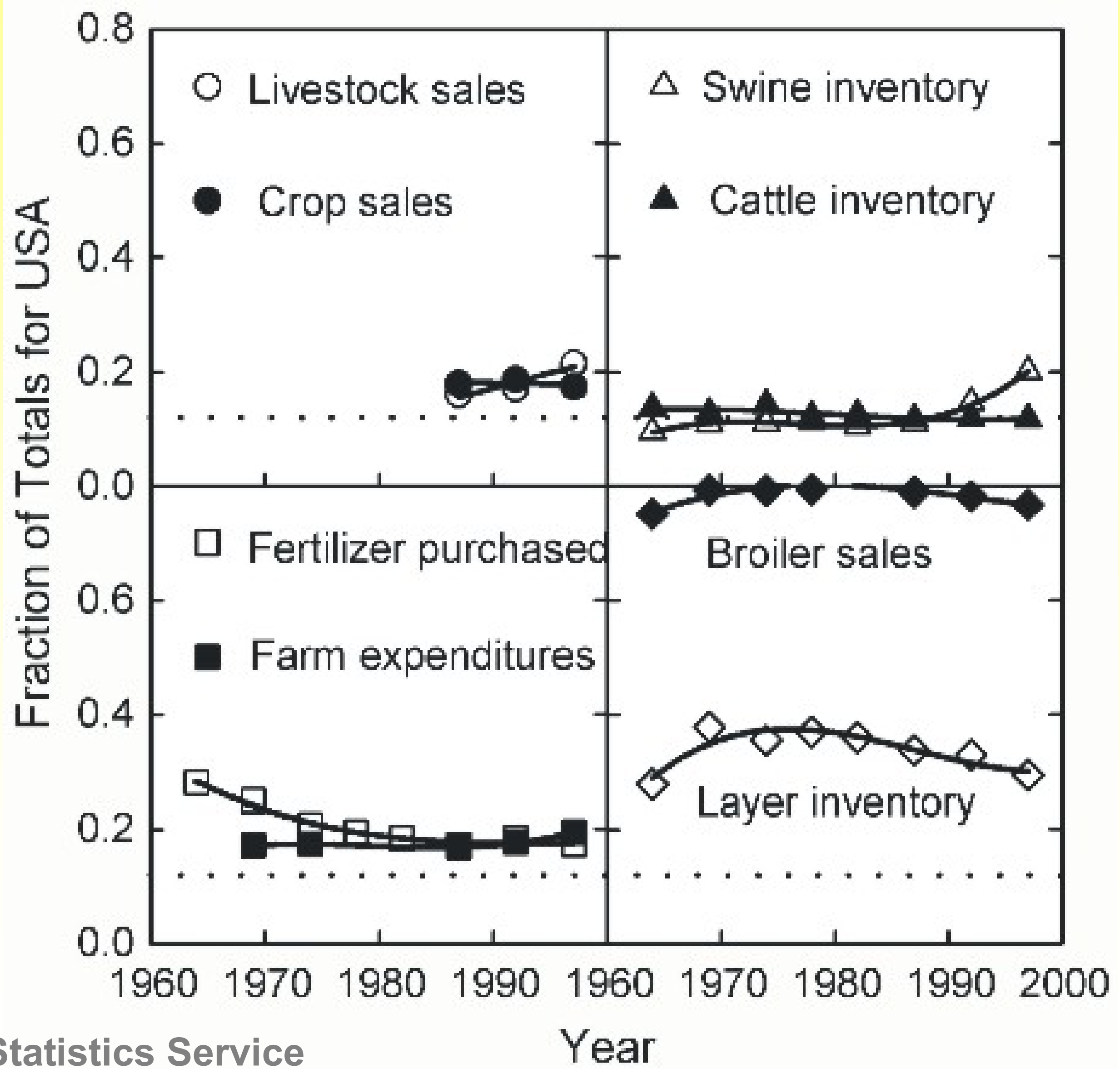


Outline

1. Characteristics of the southeastern USA
2. Greenhouse gases (GHGs) and agriculture's role
3. Management factors affecting GHGs
4. Soil organic C and nutrient cycling results from three on-going pasture experiments in Watkinsville GA

The Southeastern USA

- ✓ **Agricultural production characteristics**
  - **Fraction of national totals during past 40 years**
  - **Dotted line is fractional land area of nation in the southeastern USA**

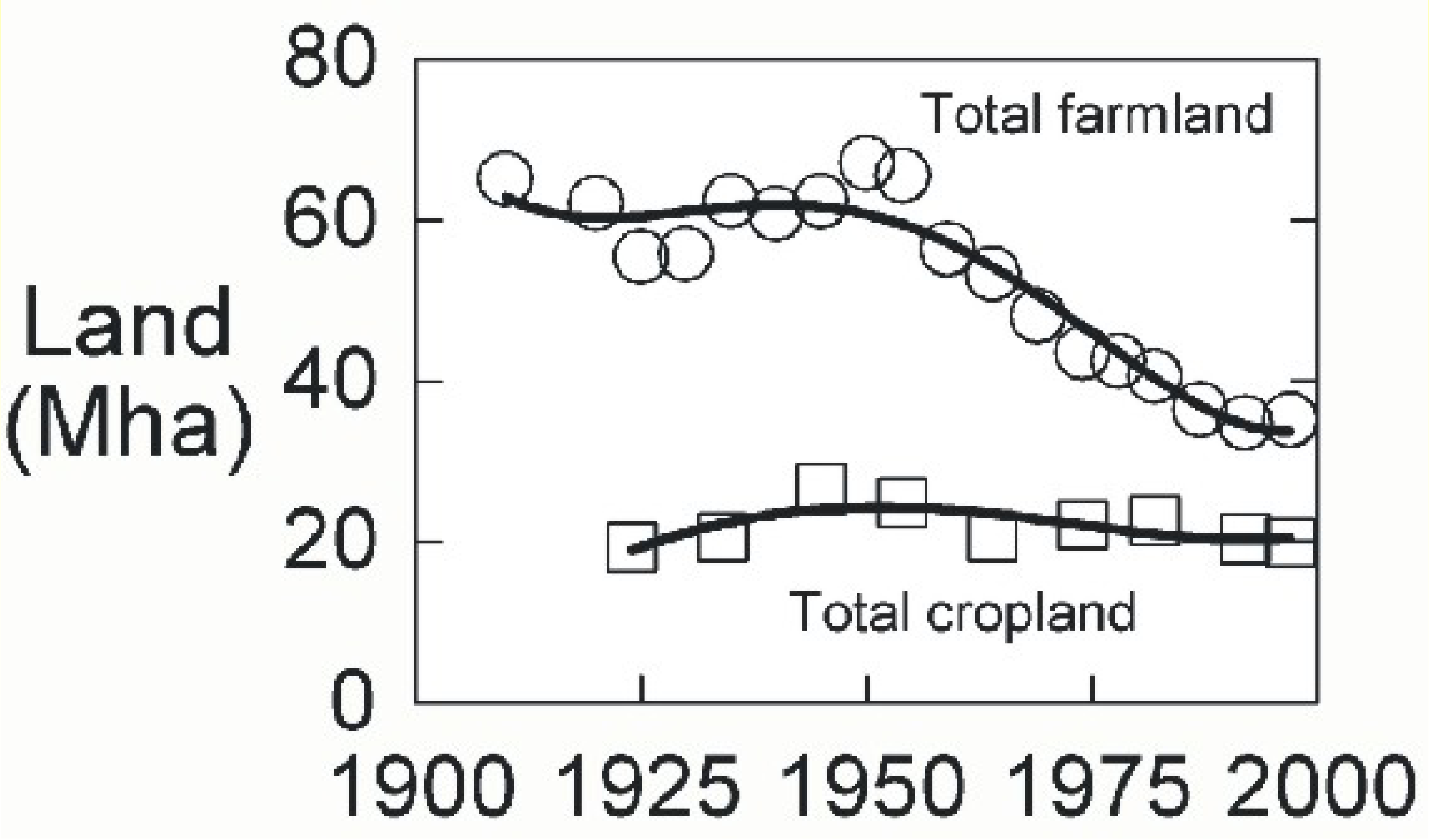


USDA-National Agricultural Statistics Service

The Southeastern USA

✓ **Agricultural production characteristics (last 100 yr)**

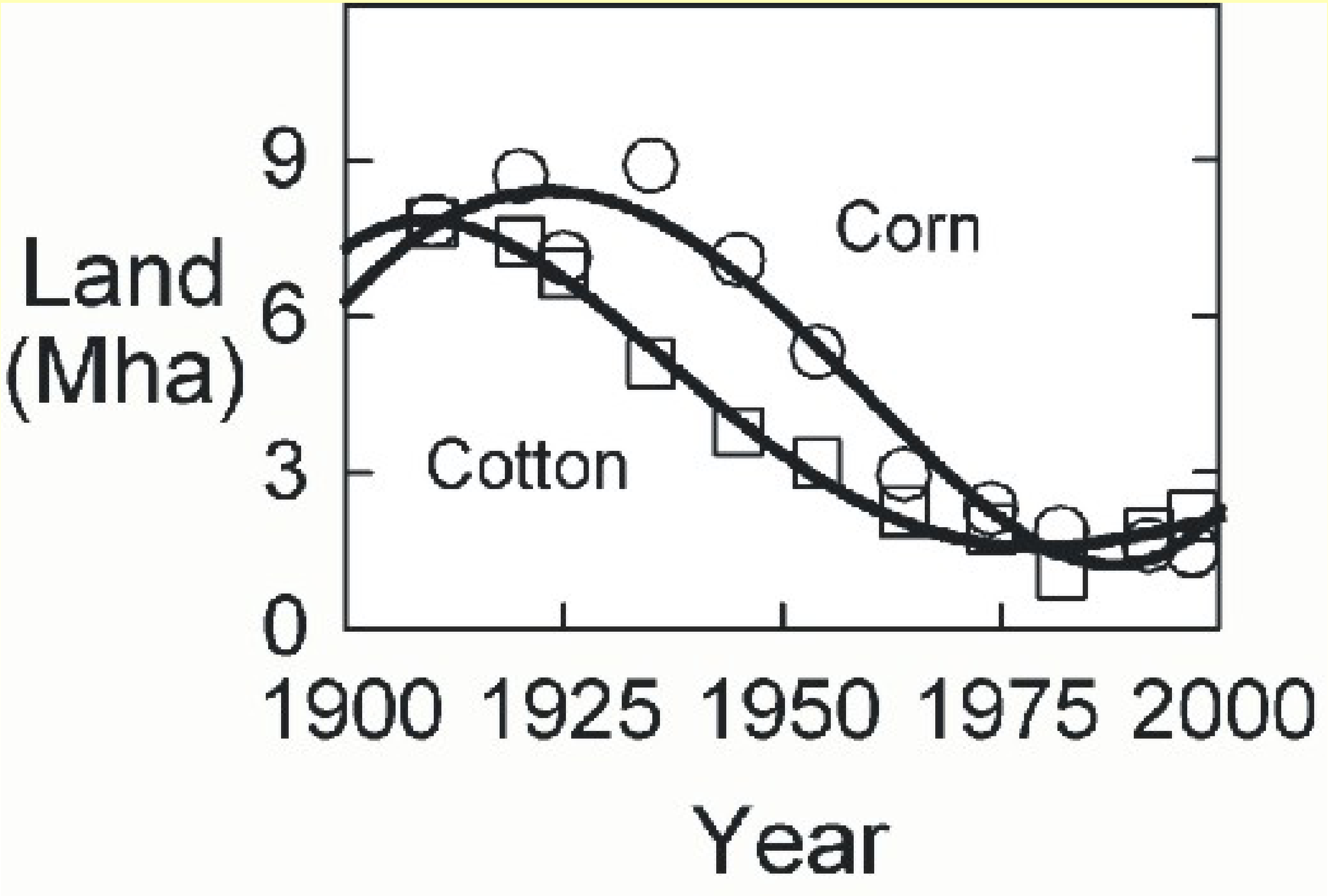
USDA-National Agricultural Statistics Service



The Southeastern USA

✓ **Agricultural production characteristics (last 100 yr)**

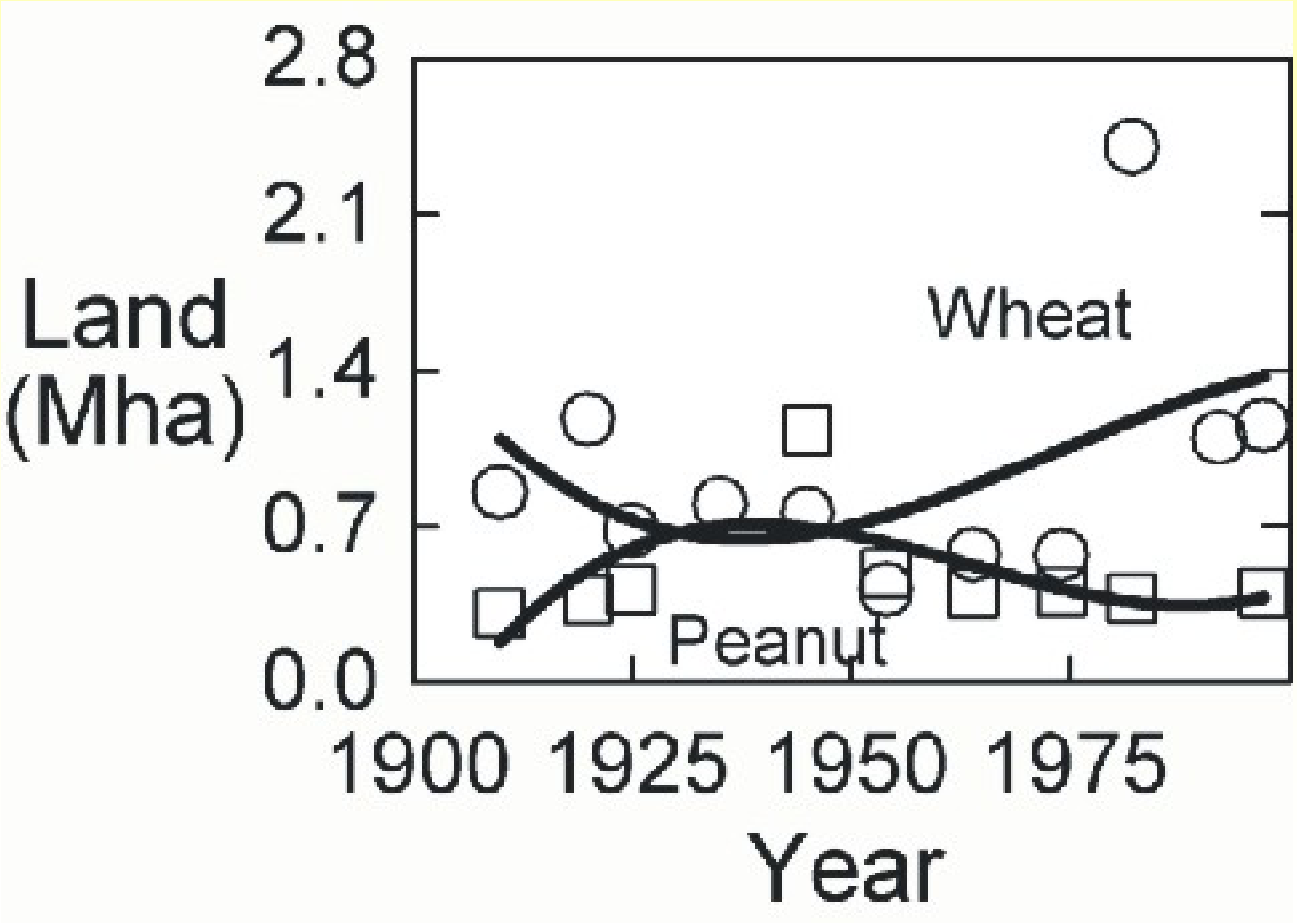
USDA-National Agricultural Statistics Service



The Southeastern USA

✓ **Agricultural production characteristics (last 100 yr)**

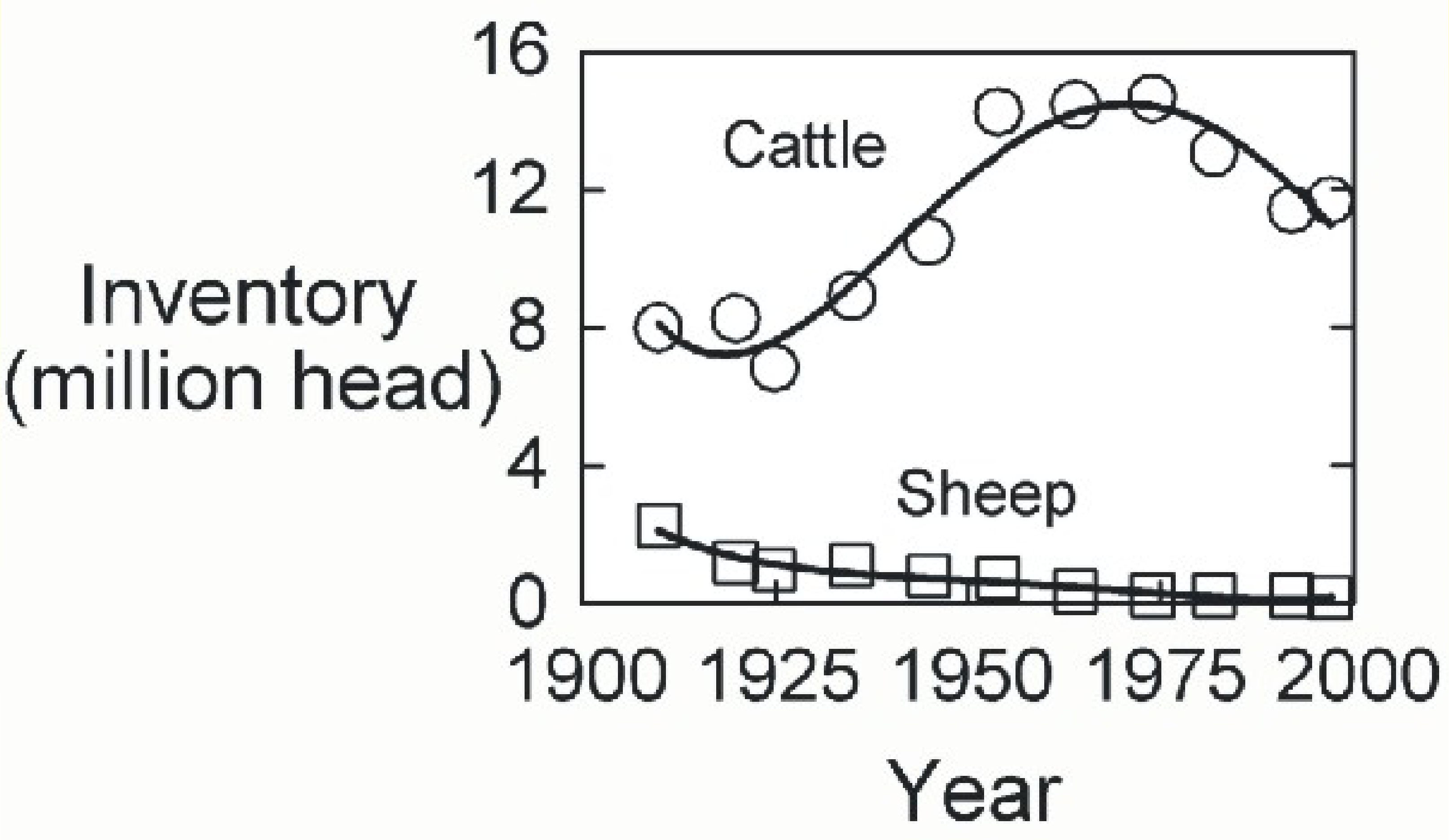
USDA-National Agricultural Statistics Service



The Southeastern USA

✓ **Agricultural production characteristics (last 100 yr)**

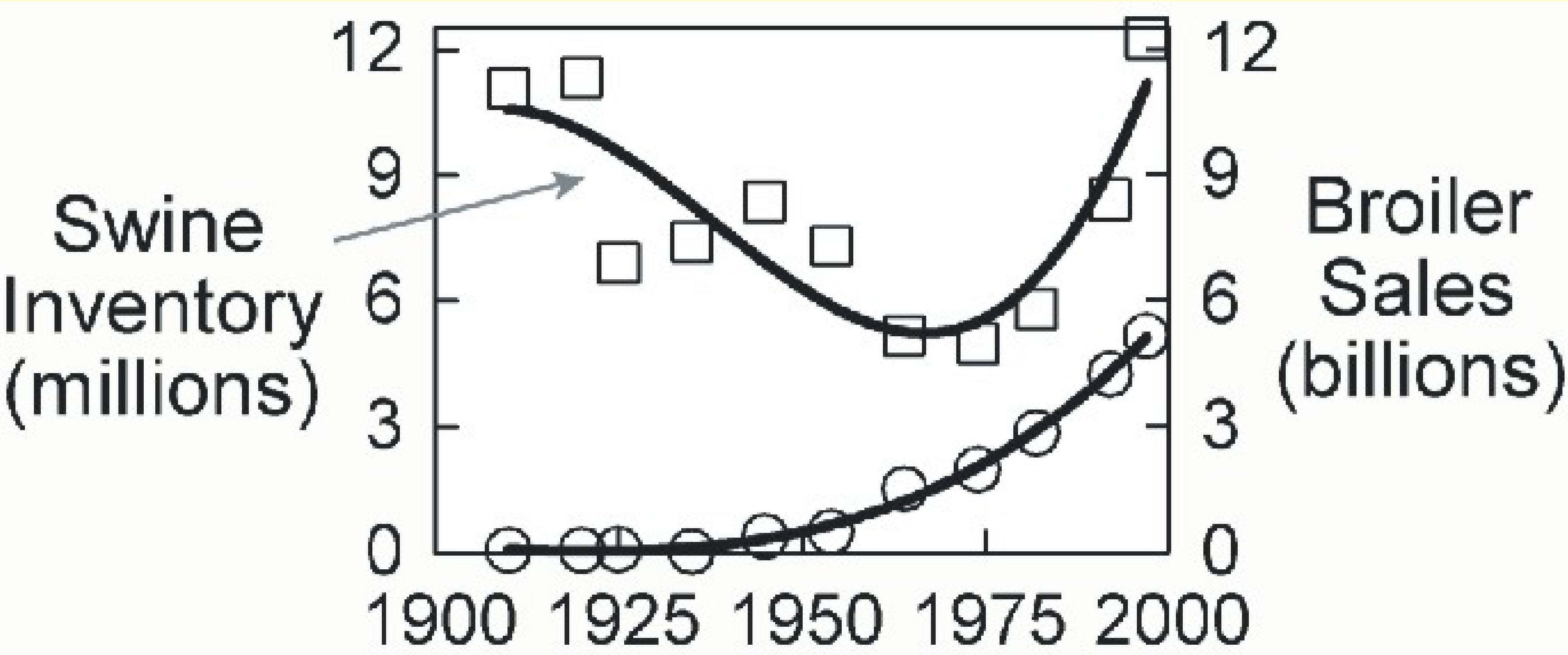
USDA-National Agricultural Statistics Service



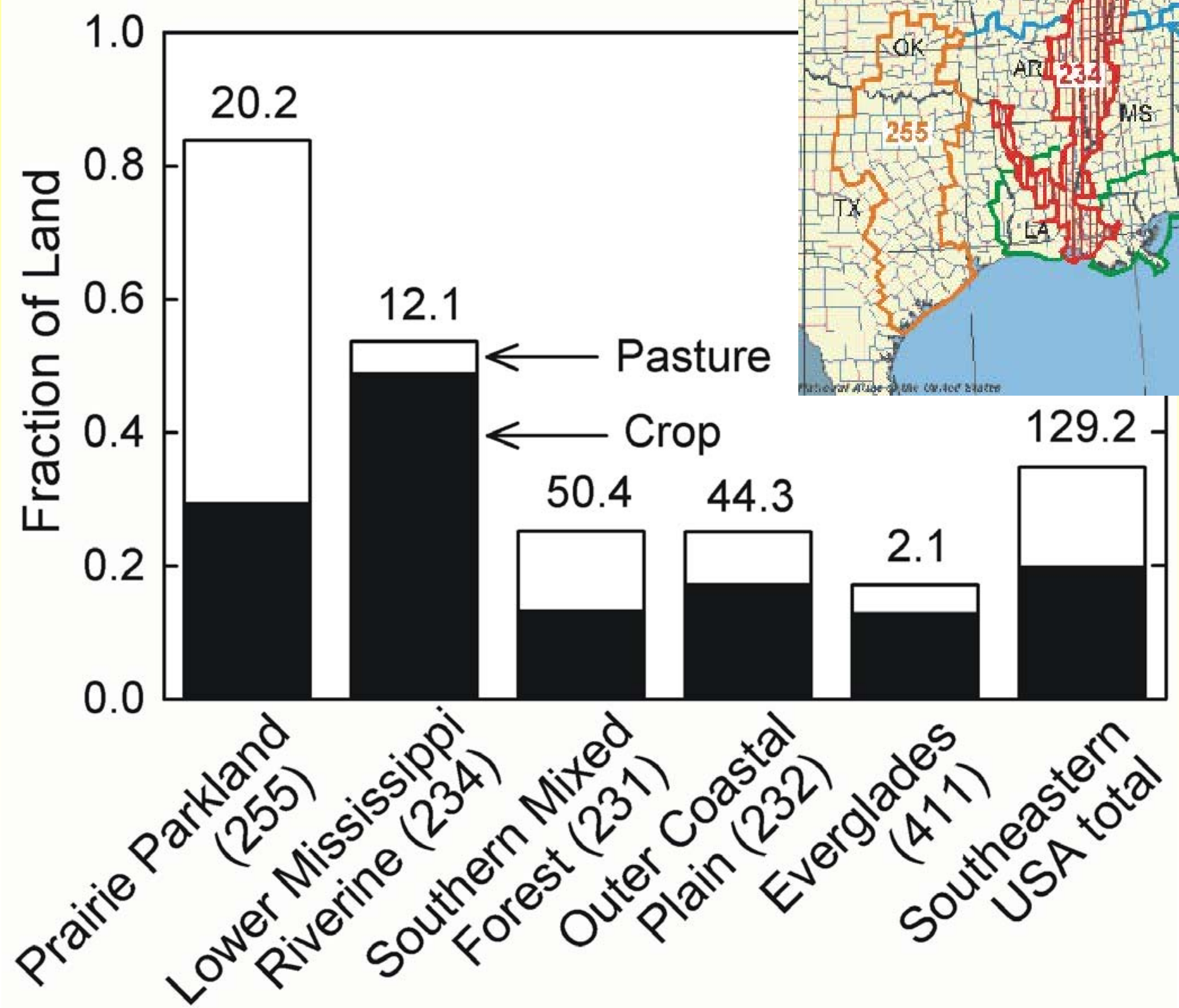
The Southeastern USA

- ✓ **Agricultural production characteristics (last 100 yr)**

  USDA-National Agricultural Statistics Service



The Southeastern USA

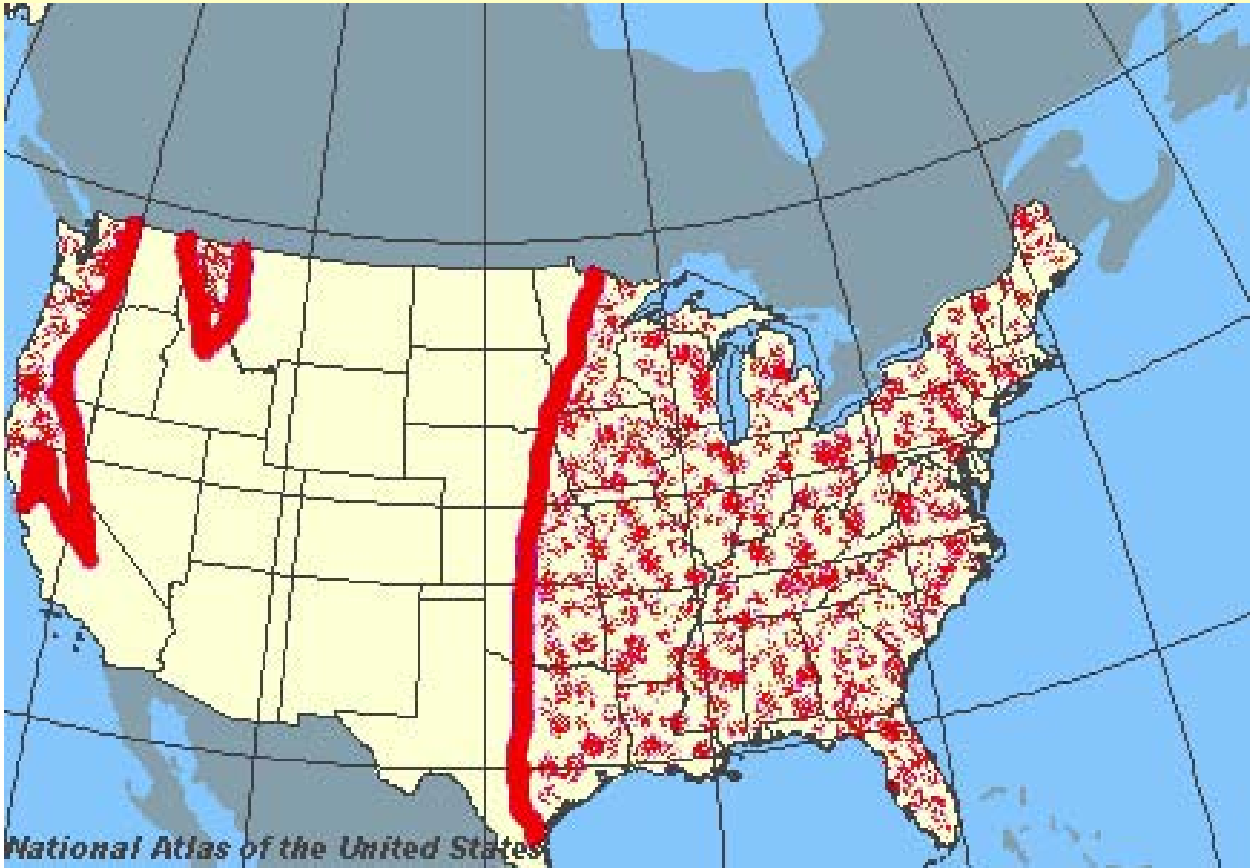


Value above bar represents total land area (Mha). Data from USDA-NASS (1997).

Characteristics of Humid Grazing Lands

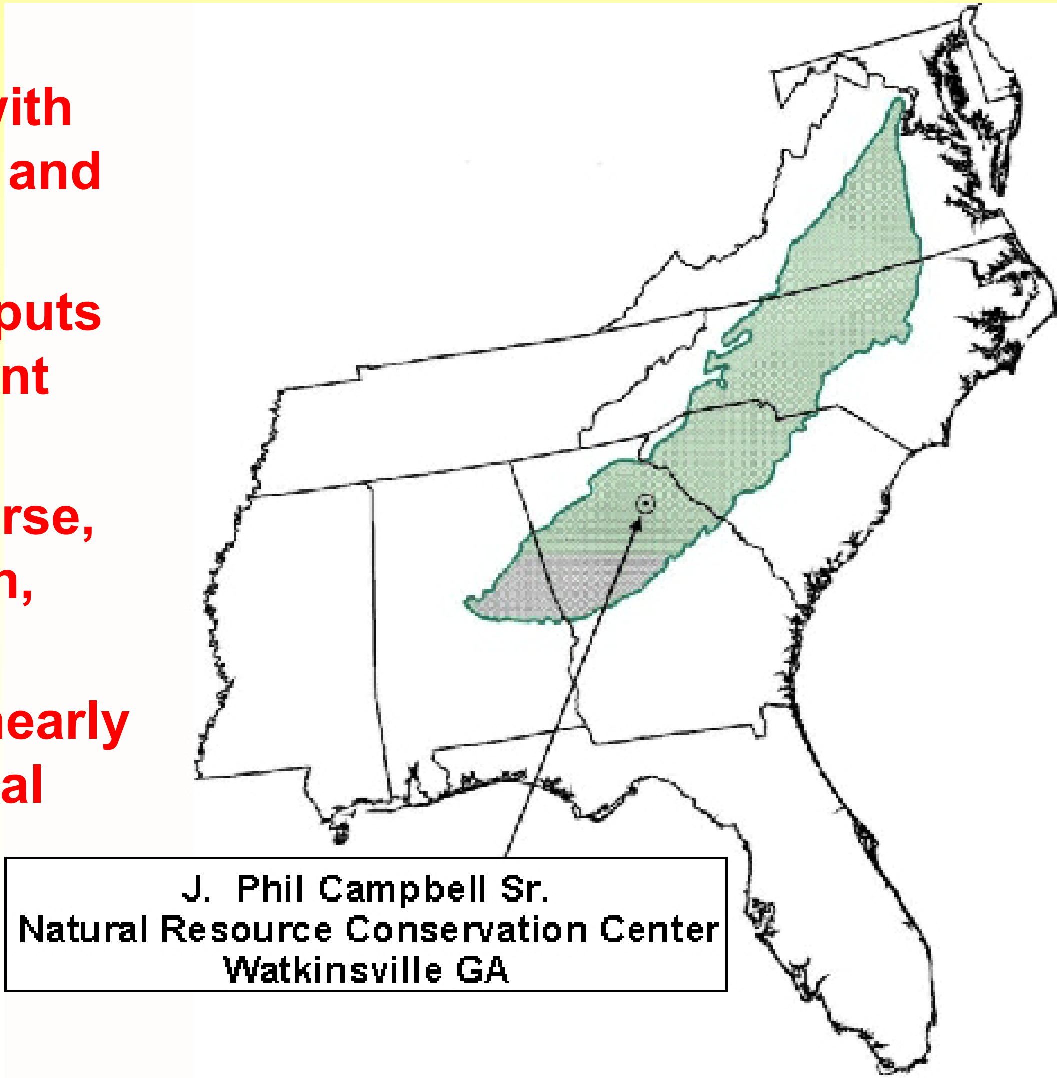
Predominantly in the eastern half of the USA and ca. 300 km of West Coast

Precipitation > 600 mm yr^{-1}



Characteristics of Humid Grazing Lands

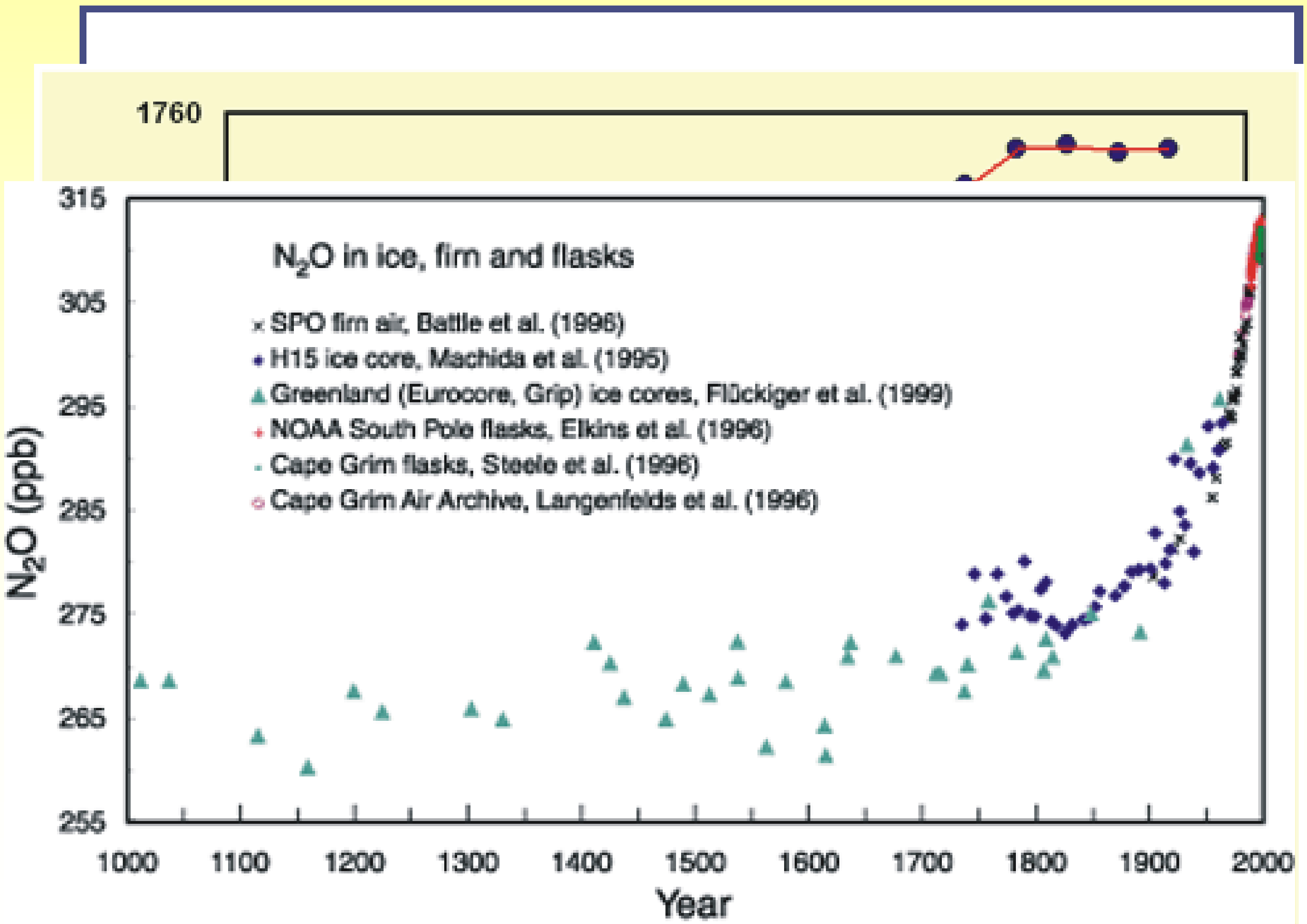
- Generally acidic soils
- Introduced plant species with high productivity potential and high forage quality
- Species that respond to inputs of fertilizer and management variables
- Utilization of forage is diverse, including intensive rotation, extensive, and haying
- In the southeastern USA, nearly year-round grazing potential (i.e., both warm- and cool-season)



Greenhouse Gases

✓ **What are they?**

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)



Greenhouse Gases

✓ Why are they important?

- Increasing concentration in the atmosphere since 1750 (Intergovernmental Panel on Climate Change, 2001)
  - CO_2 – 31% increase
  - CH_4 – 151% increase
  - N_2O – 17% increase
- Cause radiative forcing of the atmosphere, which could alter global temperature and ecosystem functioning
- Can be manipulated by type of land management

Agricultural Role in GHG Emission

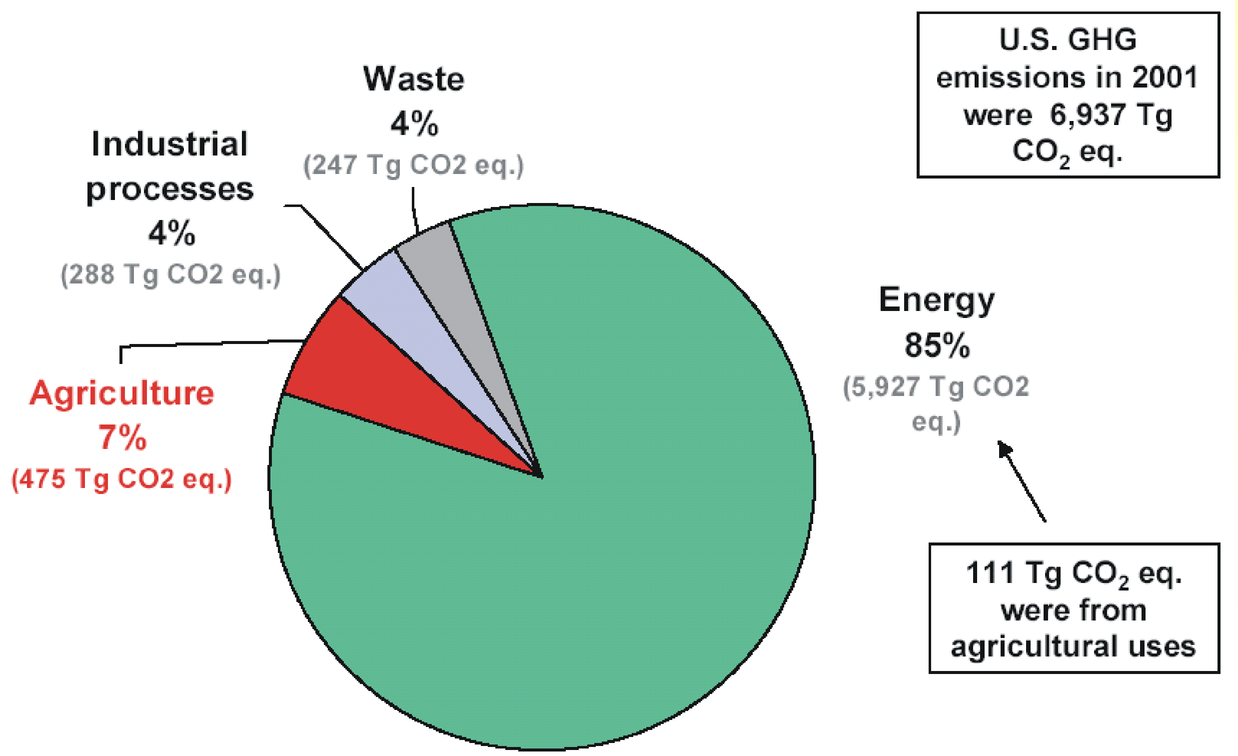
✓In the USA, <10% of total emission

Source of emission (global warming potential)

CO_2 (1)
- soil cultivation
- fuel use

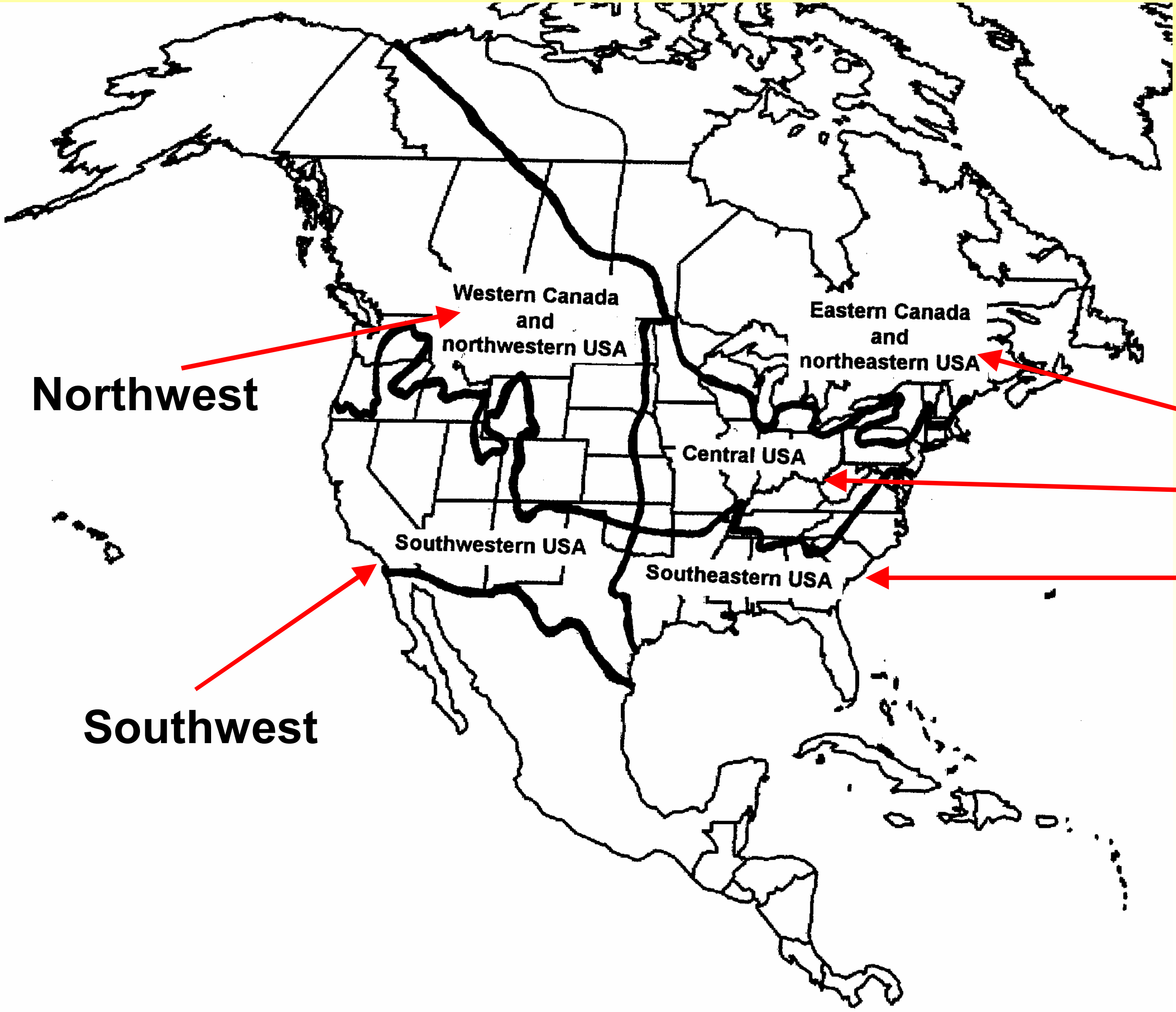
CH_4 (21)
- anaerobic soil (rice)
- enteric fermentation
- livestock waste

N_2O (310)
- fertilization
- livestock waste



USDA (2004) U.S. Agric. & Forestry GHG Invent:1990-2001

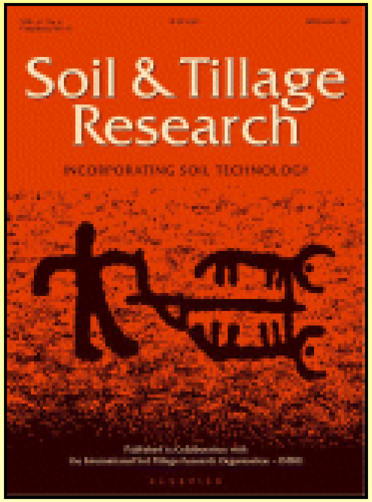
Regional Comparisons
North America



North America
divided into
5 regions

Northwest
Southwest
Northeast
Central
Southeast

Regional Comparisons
North America



Greenhouse Gas Contributions and Mitigation Potential in Agricultural Regions of North America

Special issue (mid 2005)

1. Introduction, *Franzluebbers AJ, Follett RF*
2. DAYCENT model analysis of soil N_2O…
   Del Grosso SJ, Mosier AR, Parton WJ, Ojima DS
3. Northwestern region…
   Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE
4. Northeastern region…
   Gregorich EG, VandenBygaart AJ, Rochette P, Angers DA
5. Central region…
   Johnson JMF, Reicosky DC, Allmaras RR, Sauer TJ, Venterea RT, Dell CJ
6. Southwestern region…
   Martens DA, Emmerich W, McLain JET, Johnsen TN Jr
7. Southeastern USA…
   Franzluebbers AJ
8. …irrigated Vertisol in central Mexico
   Martens DA, Emmerich W, McLain JET, Johnsen TN Jr
9. Research and implementation needs…
   Follett RF, Shafer SR, Jawson MD, Franzluebbers AJ
10. GRACEnet
   Jawson MD, Shafer SR, Franzluebbers AJ, Parkin TB, Follett RF

Regional Comparisons
North America

Management	NW	NE	C	SW	SE	Conant
	----------	----------	Mg C ha^{-1} yr^{-1}	----------	----------	----------
Soil organic C sequestration						
N fertilizer	0.09	.	.	.	0.18	0.30
Conversion of crop land to grassland	0.94	.	0.56	0.32	1.03	1.01
Grazed *vs* ungrazed Grassland	0.16	.	.	-0.03	0.76	0.35
N_2O emission (in C equivalence)						
All agriculture	-0.38	-0.41	.	-0.91	.	
Grass systems	-0.08	-0.15	.	-0.91	.	
DAYCENT (Del Gross et al.)	-0.24	-0.25	-0.36	-0.32	-0.36	

Agricultural Mitigation Strategies

✓Increase soil organic carbon sequestration

- Conversion of land to less disturbed usage
- Conservation tillage
- Pasture development

✓Reduce fossil fuel use

- Tractor time
- Grain drying
- Irrigation

✓Reduce nitrogen fertilizer saturation

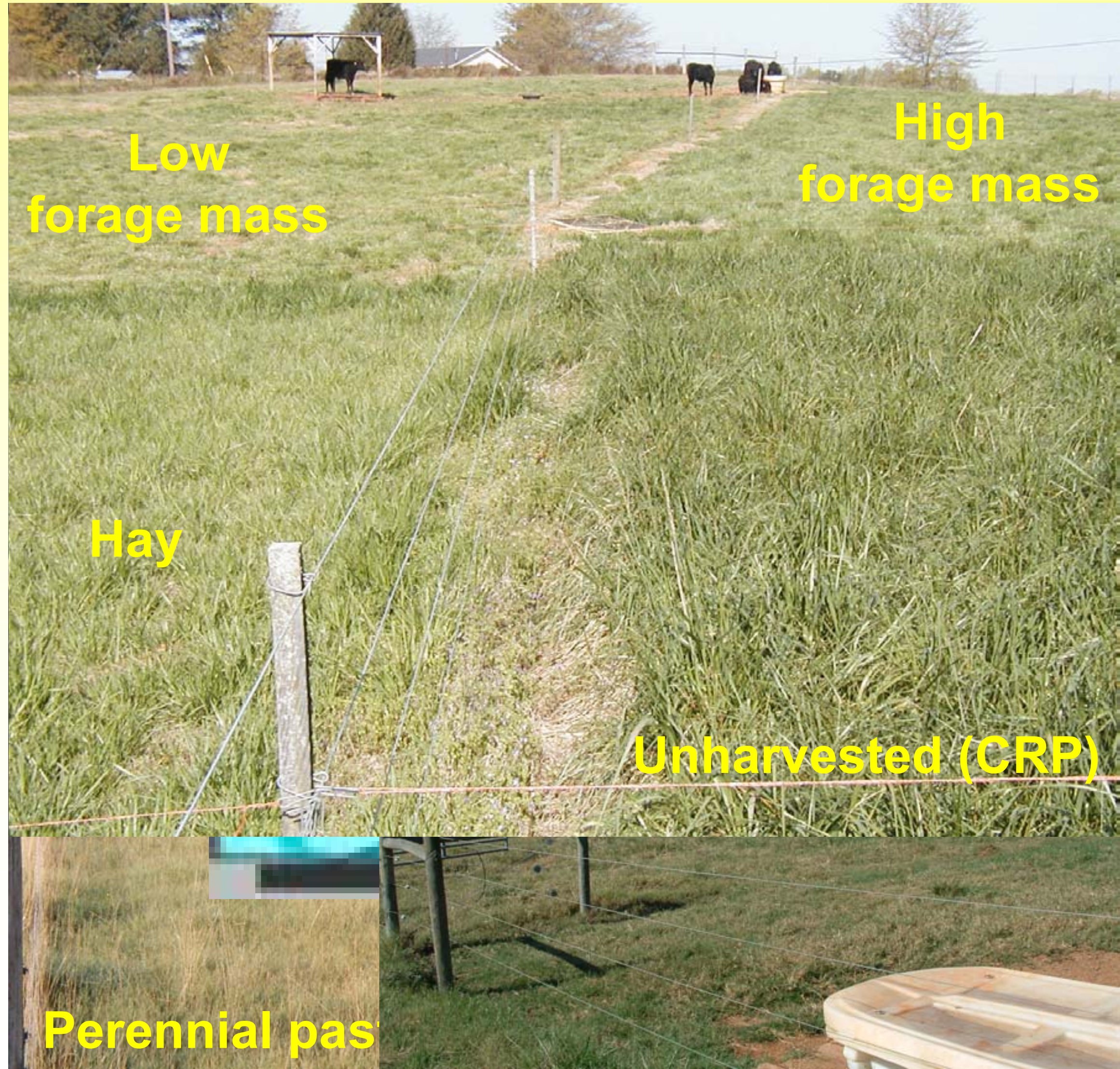
- Reduce opportunities for nitrous oxide emission

✓Increase cropping intensity

- Sequester more C per unit of input costs

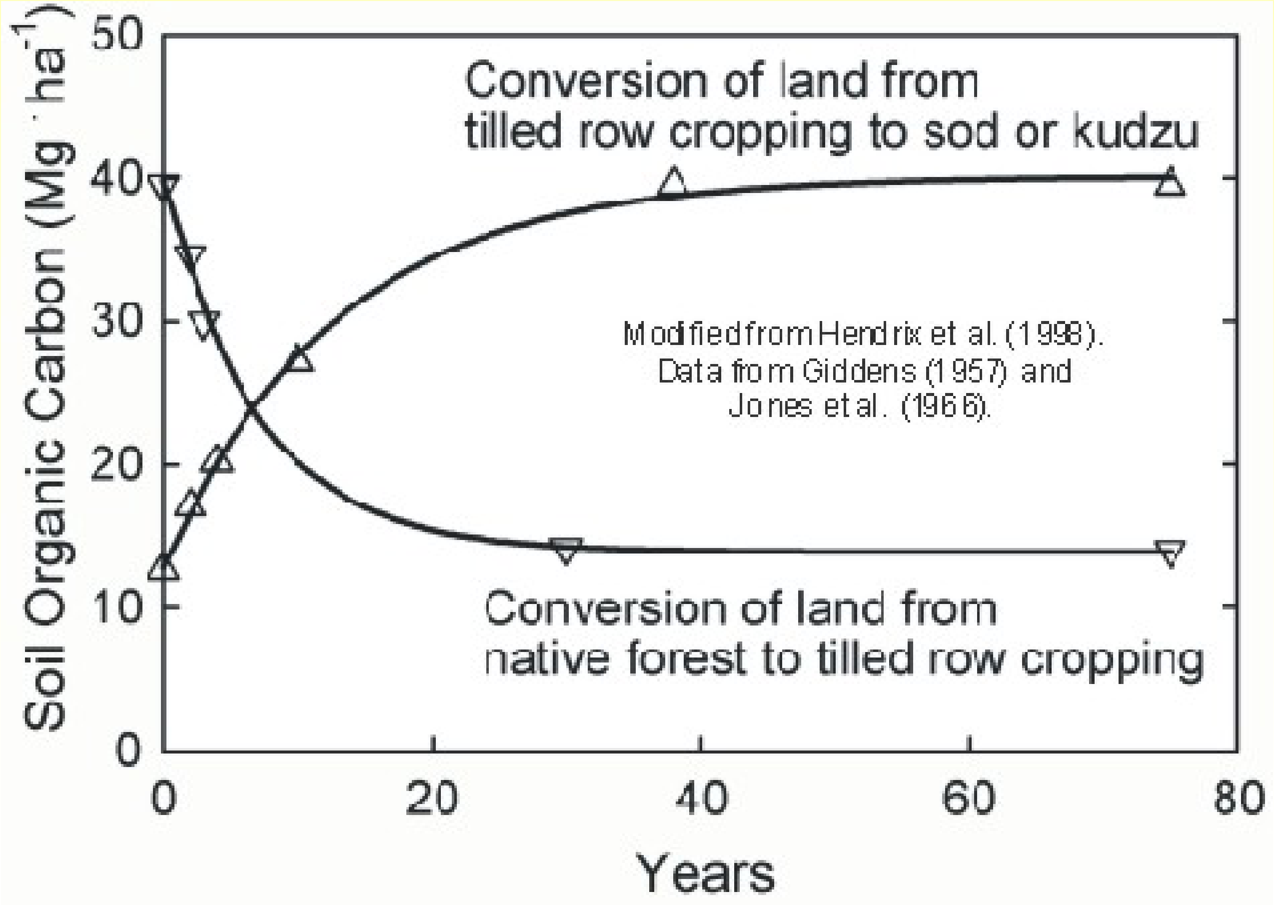
Management Factors Affecting Soil Organic C

- Land use
  - Forest
  - Grass
  - Crops
- Forage type
  - Cool or warm season
  - Annual or perennial
  - Endophyte
- Fertilization
  - Inorganic N-P-K
  - Animal manures
- Utilization
  - Hay
  - CRP
  - Grazing pressure



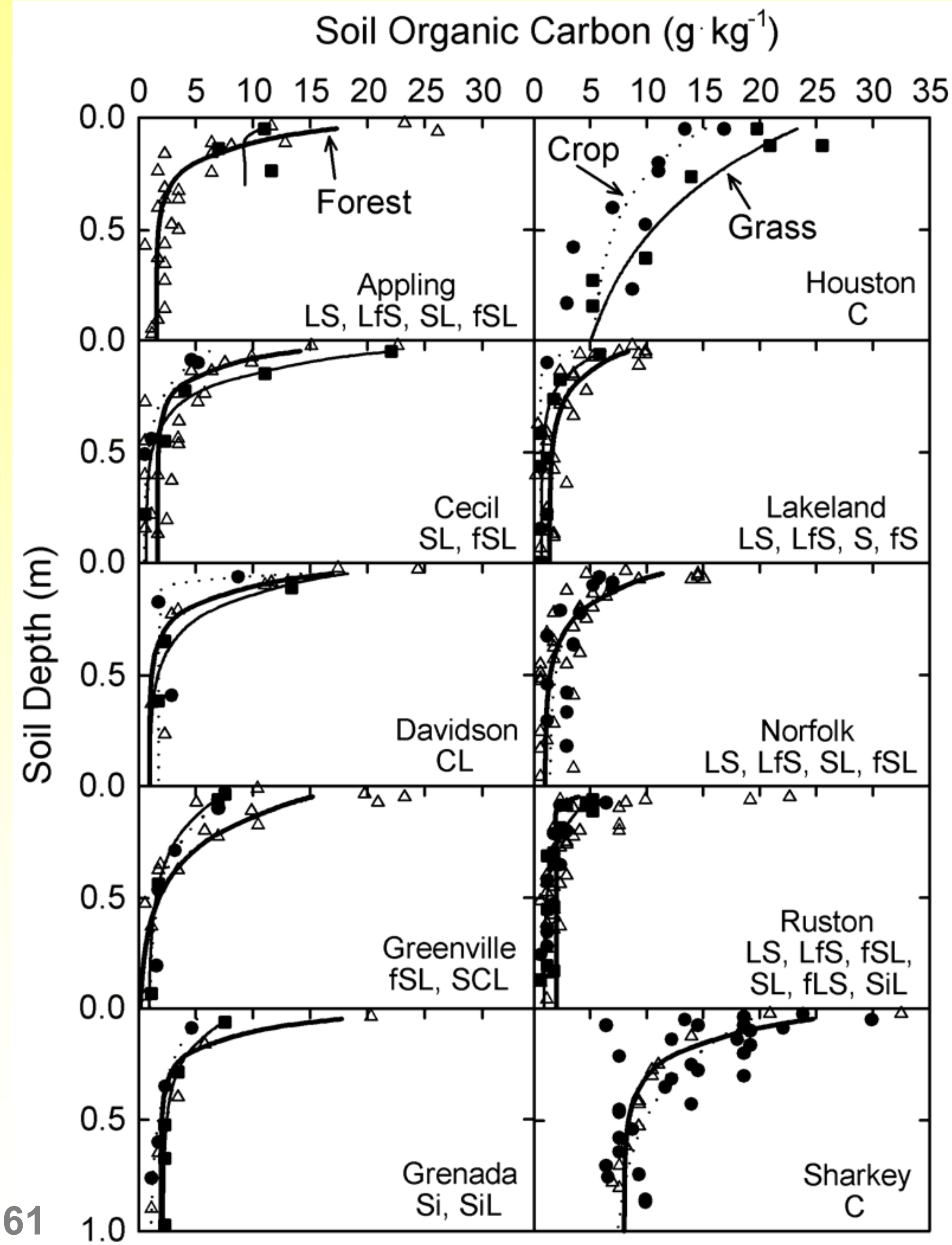
Land Use

- ✓ Conversion of forest to conventionally tilled cropland can reduce SOC by >50%



Land Use

- ✓ Under forest and grass, soil organic C is typically stratified with depth.
- ✓ Below 0.5 m, soil organic C is typically <5 g kg^{-1}, except in high-clay-content soils.



McCracken (1959) South. Reg. Bull. 61

Land Use

✓ How important are grasslands to C sequestration compared with other land uses?

Land use	Land area	Above-ground	Soil	Total
		---------------- C stocks ---------------		
	10^6 km^2	---------------- kg m^{-2} ---------------		
Tropical/temperate forest	28	9.7	11.3	21.0
Cropland	8	0.2	8.0	8.2
Tropical/ temperate grassland	35	2.1	16.0	18.1

From Intergovernmental Panel on Climate Change Special Report on Land Use, Land-Use Change and Forestry

Land Use

Study	Depth	Forest	Grass	Crop	Significance
Eastern Texas Laws and Evans (1949), Potter et al. (1999)	30	--	88 ± 18	57 ± 8	<0.01
AL-AR-FL-GA-LA-MS-NC-SC-TX-VA McCracken (1959)	25	31 ± 12	31 ± 16	23 ± 15	0.04
Maryland Islam and Weil (2000)	15		32 ± 10	20 ± 7	0.01
Alabama Fesha et al. (2002), Torbert et al. (2004)	25 ± 6	60 ± 21	48 ± 26	34 ± 8	0.03
Mississippi, Georgia Rhoton and Tyler (1990), Franzluebbers et al. (2000)	25 ± 7	47 ± 2	38	22 ± 6	0.08
Mean	24 ± 6	49.9 a	47.4 a	31.1 b	

Franzluebbers (2005) Soil Till. Res.

Pastures

✓ Grass establishment affects soil organic C

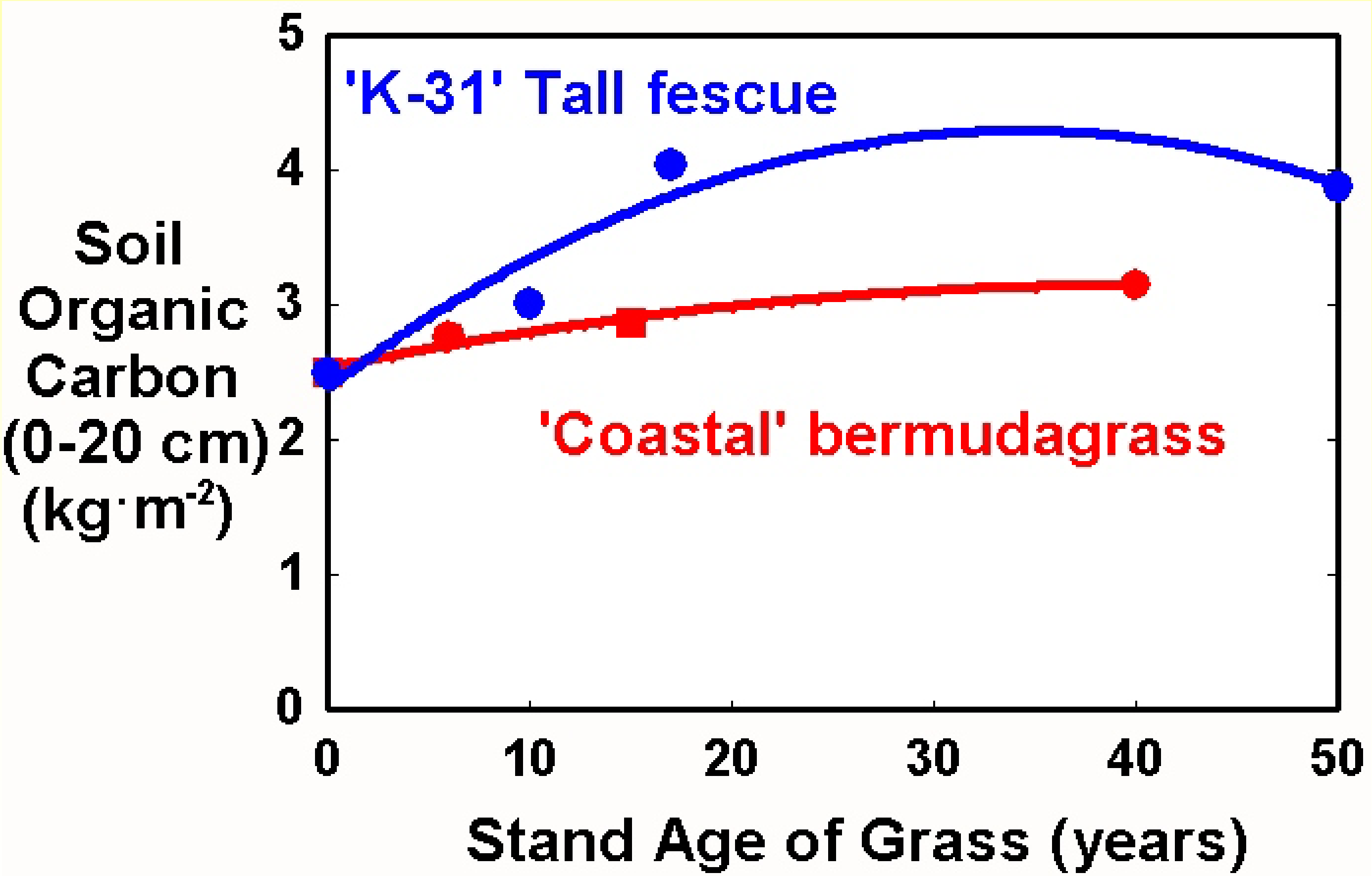
Effect of grass establishment

Number of studies	12
Duration of comparison (yr)	15 ± 17
SOC sequestration ($Mg\ ha^{-1}\ yr^{-1}$)	1.03 + 0.90

Rate of SOC sequestration was 2.5 times greater than with NT cropping

Franzluebbers (2005) Soil Till. Res.

Forage Type
Cool- *vs* Warm- Season Grasses



Soil organic C sequestration rate during 25 years

0.78 Mg ha^{-1} yr^{-1}

0.26 Mg ha^{-1} yr^{-1}

Different opportunities for growth during the year.

Franzluebbers et al. (2000) Soil Biol. Biochem. 32:469-478.

Fertilization

✓ **Poultry manure affects soil organic C**

	SOC ($Mg\ ha^{-1}$)	
Effect of manure application	**Without**	**With**
2-yr studies (n=6)	19.8 ± 8.9	19.6 ± 8.4
11 ± 8-yr studies (n=8)	30.6 ± 11.4	36.8 ± 10.6
SOC sequestration for all ($Mg\ ha^{-1}\ yr^{-1}$)	0.26 ± 2.15	
SOC sequestration for >2-yr studies	0.72 ± 0.67	

✓ Conversion of C in poultry litter to SOC was 17 ± 15%.

✓ Manure application transfers C from one land to another.

Franzluebbers (2005) Soil Till. Res.

Fertilization
Inorganic *vs* Organic Source

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was compared between inorganic and organic fertilization.

Management	Rate of SOC Sequestration (Mg ha^{-1} yr^{-1})
Inorganic fertilizer	0.29
Organic fertilizer	0.28

Fertilization
Rate of N-P-K Application

- Long-term effect of low (134-15-56 kg N-P-K ha^{-1} yr^{-1}) versus high (336-37-136 kg N-P-K ha^{-1} yr^{-1}) fertilization of tall fescue pastures on SOC

At the end of 15 years

Soil Depth	Fertilizer Rate Low		Fertilizer Rate High
	---- Mg ha^{-1} ---		
0 to 2.5	10.2		10.9
2.5 to 7.5	11.0	<	11.8
7.5 to 15	11.0	<	11.7
15 to 30	12.8		13.1
0 to 30	45.0	<	47.6

Schnabel et al. (2001) In: Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect

At the end of 20 years

Soil Depth	Fertilizer Rate Low		Fertilizer Rate High
	---- Mg ha^{-1} ---		
0 to 3	11.7		13.1
0 to 6	19.1		20.8
0 to 12	29.2	<	31.3
0 to 20	37.6	<	40.3

Franzluebbers and Stuedemann (2005) Soil Sci. Soc. Am. J. (Mar-Apr).

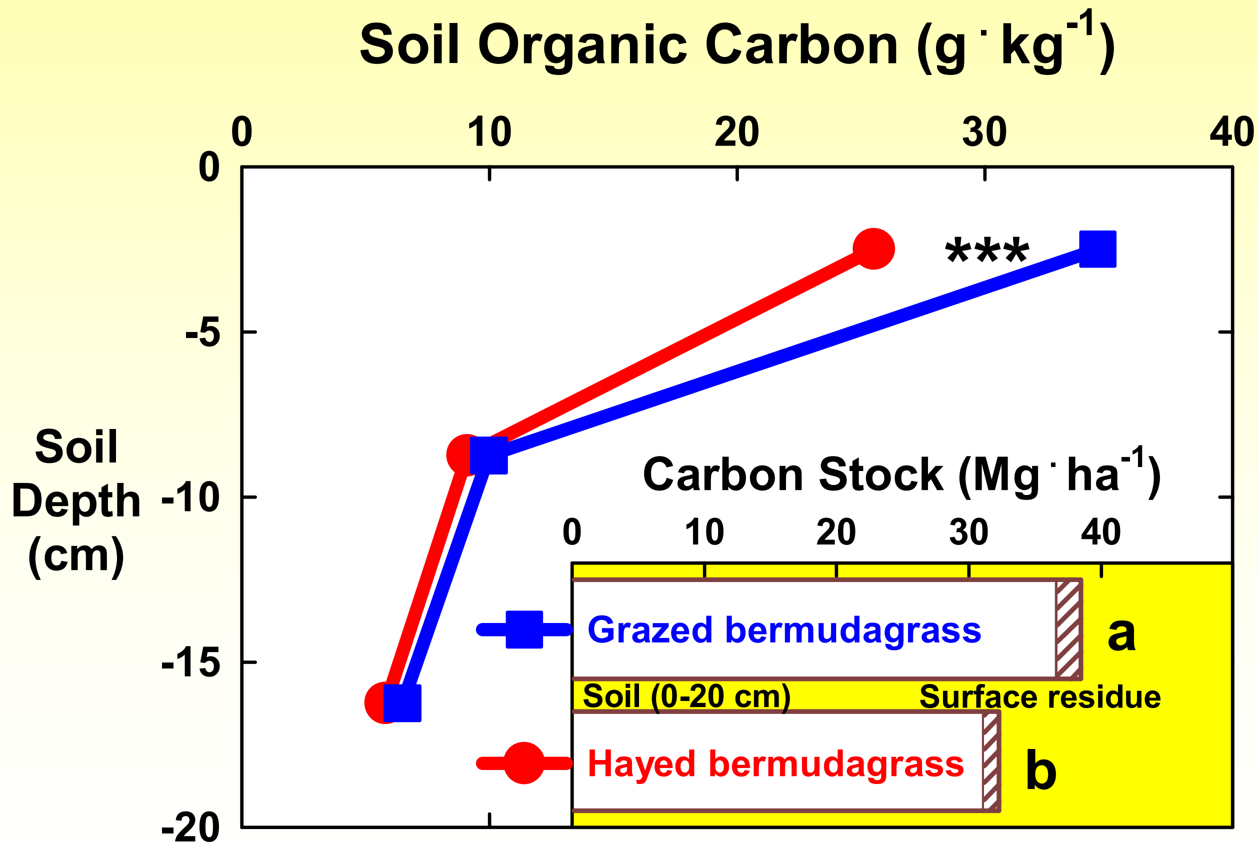
Fertilization
Nitrogen and Phosphorus Application

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was assessed with improved fertilization (i.e., a higher N and/or P rate) to improve forage production.

	Mean Annual Soil C Change (%)	
Biome	Based on Concentration	Based on Content
More aridic		
Desert	NA	2.0
Grassland	1.3	3.8
More udic		
Woodland	4.0	1.9
Forest	2.2	0.4

Forage Utilization
Grazed *vs* Hayed

✓ Long-term pasture survey (15- to 19-year old fields, 3 each)



Surface residue
1.2
1.8
Soil (0-20 cm)
31.1
38.0

Difference
7.5
Mg ha^{-1} yr^{-1}

Franzluebbers et al. (2000) Soil Biol. Biochem. 32: 469-478.

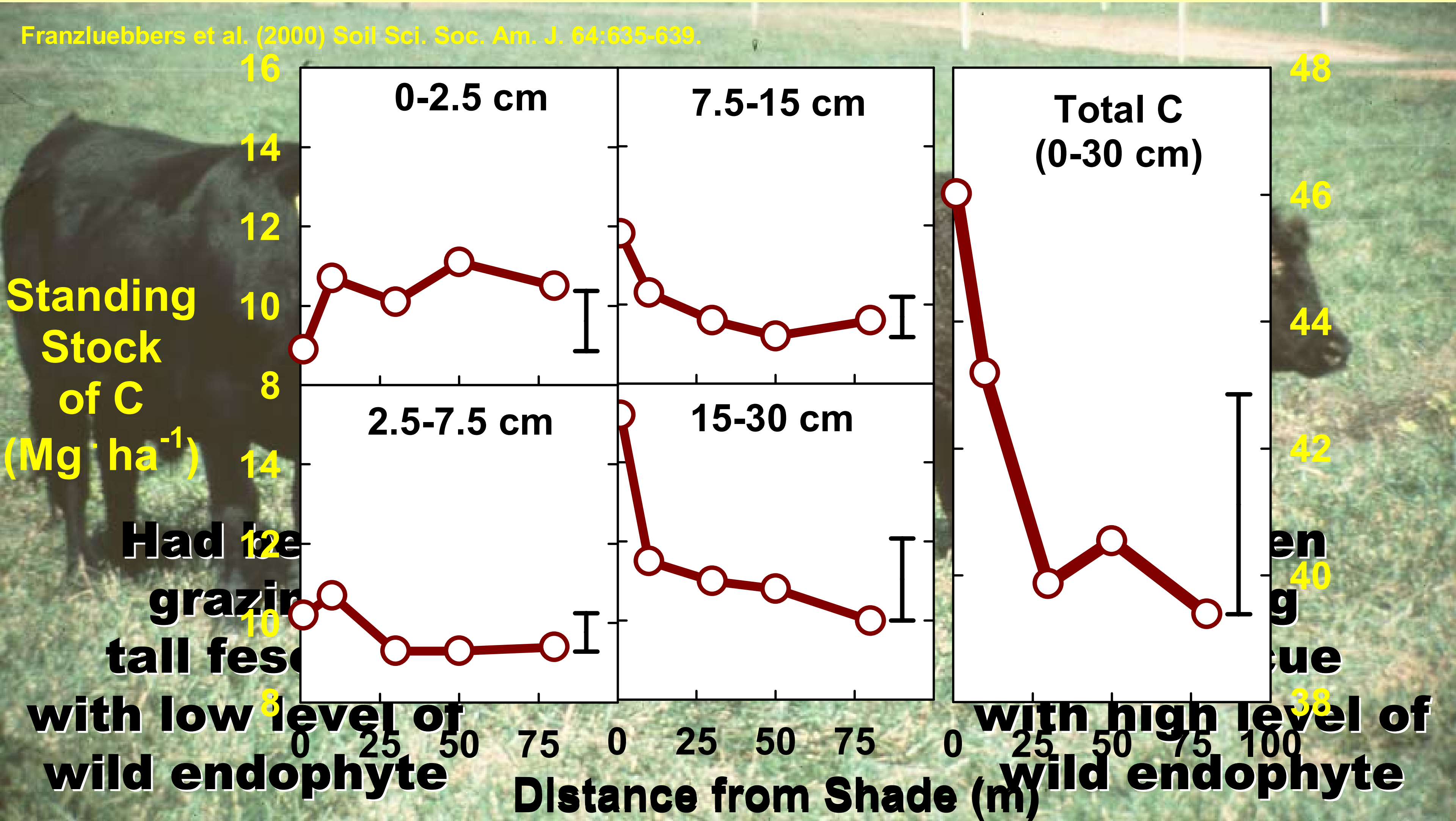
Forage Utilization
Grazed *vs* Ungrazed

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was assessed with moderate grazing pressure compared with less than optimal grazing pressure.

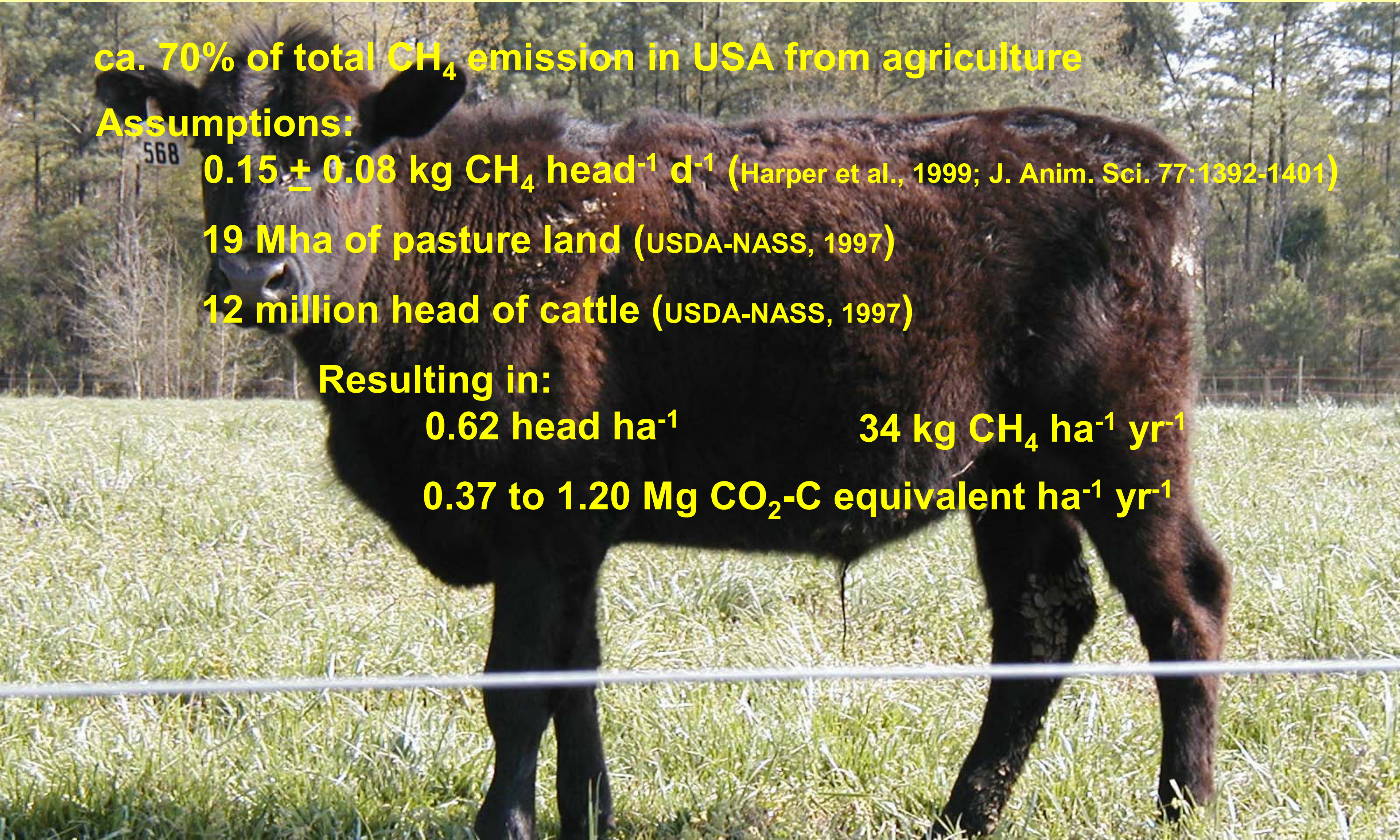
	Mean Annual Soil C Change (%)	
Biome	Based on Concentration	Based on Content
More aridic		
Desert	-0.1	NA
Shrubland	1.8	NA
Grassland	0.0	0.9
More udic		
Woodland	8.0	5.6
Forest	0.9	0.0
Rainforest	7.3	0.4

Forage Utilization
Animal Behavior

At the end of 8 to 15 years of grazing K-31 tall fescue



Forage Utilization
Methane Emission



ca. 70% of total CH_4 emission in USA from agriculture

Assumptions:

- 0.15 ± 0.08 kg CH_4 head^{-1} d^{-1} (Harper et al., 1999; J. Anim. Sci. 77:1392-1401)
- 19 Mha of pasture land (USDA-NASS, 1997)
- 12 million head of cattle (USDA-NASS, 1997)

Resulting in:

- 0.62 head ha^{-1}
- 34 kg CH_4 ha^{-1} yr^{-1}
- 0.37 to 1.20 Mg CO_2-C equivalent ha^{-1} yr^{-1}

Trace-Gas Emissions

- ✓ **Nitrous oxide**
  - Limited data available

Study	Control	Poultry Litter
	Nitrous oxide emission (kg N_2O-N ha^{-1})	
Marshall et al. (2001) Nutr. Cycl. Agroecosys. 59: 75-83		
Coastal Plain (AL)	6.3	4.9
Piedmont (GA)	0.3	1.9
Cumberland Plateau (TN)	1.9	1.5
Thornton et al. (1998) Atmos. Environ. 32:1623-1630		
Tennessee Valley (AL)	0.5	3.9
	urea 3.0	composted 1.6
Groffman (1985) Soil Sci. Soc. Am. J. 49:329-334		
Athens GA (cropping system)	CT 579	NT 505
Walker et al. (2002) Chemosphere 49:1389-1398		
Dillard GA (riparian forest)	grazed 25	ungrazed 24

Trace-Gas Emissions

✓ **Methane**

- Flux estimates in other regions indicate potential for soil with high organic matter to act as a sink for CH_4
- No data on soil CH_4 uptake in the southeastern USA

Harper et al. (2000) J. Environ. Qual. 29:1356-1365

Cordele GA (swine confinement, micrometeorological assessment)

Lagoon	Total gas flux	N_2	CO_2	N_2O	CH_4
	kg ha^{-1} d^{-1}	----------------	%	----------------	
First (3.5 ha)	159	15	5	0	79
Second (1.3 ha)	21	54	2	0	26
Third (3.5 ha)	20	59	1	3	13
Fourth (1.3 ha)	17	69	1	18	8

On-Going Studies in Watkinsville GA

- ✓ Salem Road grazing study, Farmington GA
- ✓ Phase 1: 1994-1998, 'Coastal' bermudagrass
- ✓ Phase 2: 1999-2005, interseeded 'Georgia 5' tall fescue
- ✓ 4 harvest regimes
  - Hayed
  - Low forage mass
  - High forage mass
  - Unharvested

Full ↕ None — Forage utilization

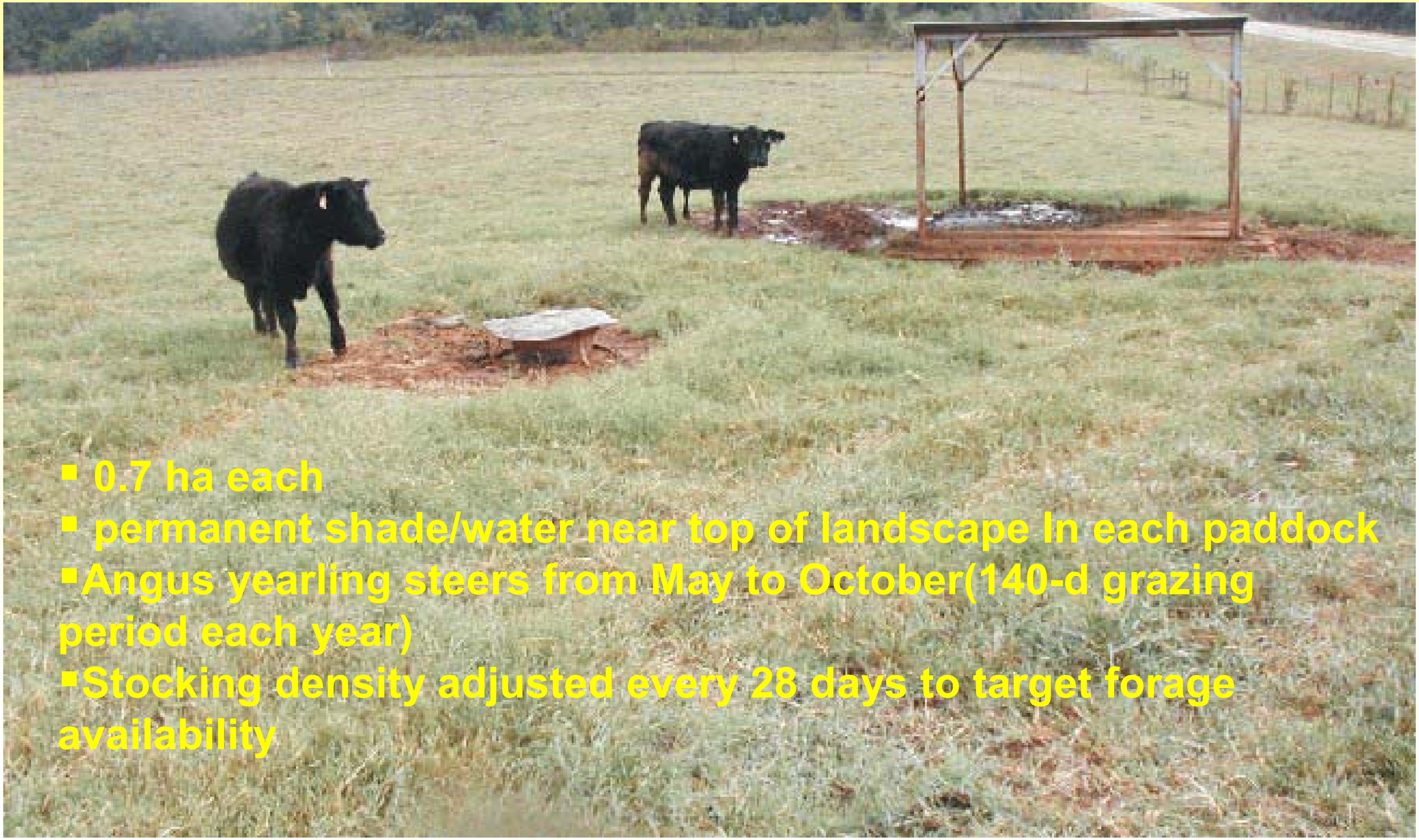
- ✓ 3 fertilization regimes (200 kg N ha^{-1} yr^{-1})
  - Inorganic only
  - Clover+inorganic
  - Broiler litter
- ✓ 3 replications

Phase 2

- Inorganic only
- 1x broiler litter + inorganic, P based
- 3x broiler litter, N based

Salem Road Grazing Study

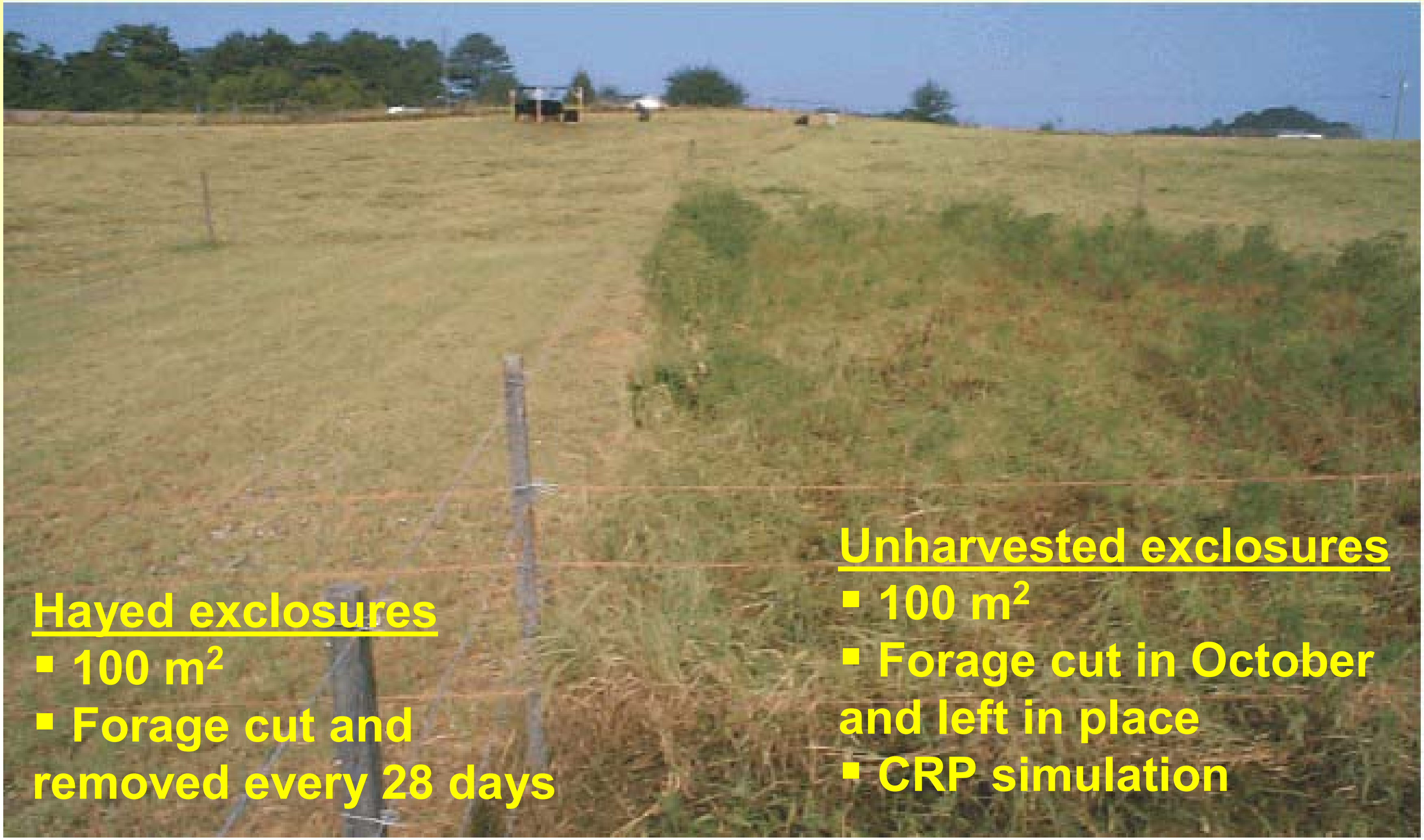
✓Grazed paddocks



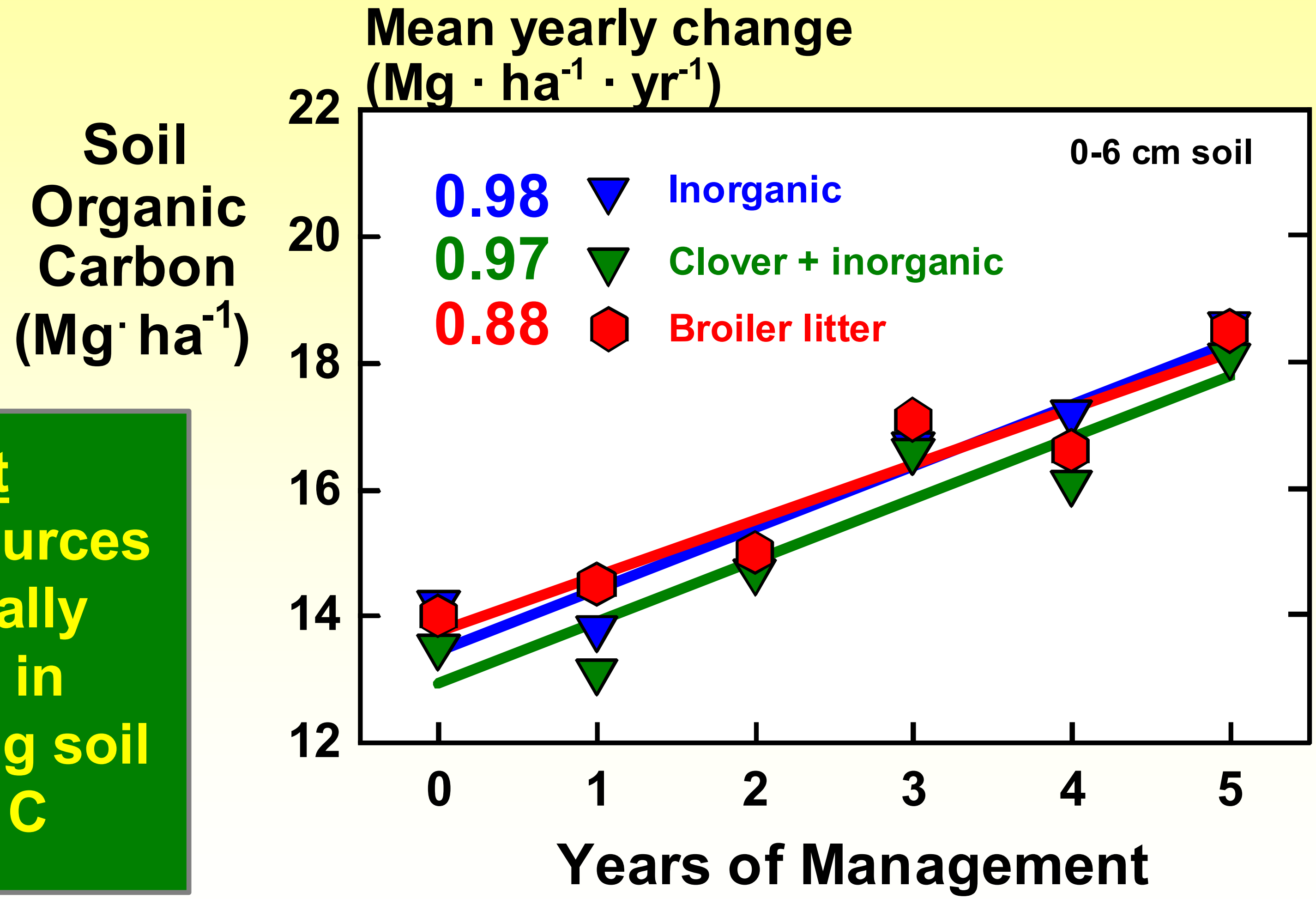
- 0.7 ha each
- permanent shade/water near top of landscape In each paddock
- Angus yearling steers from May to October(140-d grazing period each year)
- Stocking density adjusted every 28 days to target forage availability

Salem Road Grazing Study

✓Exclosures



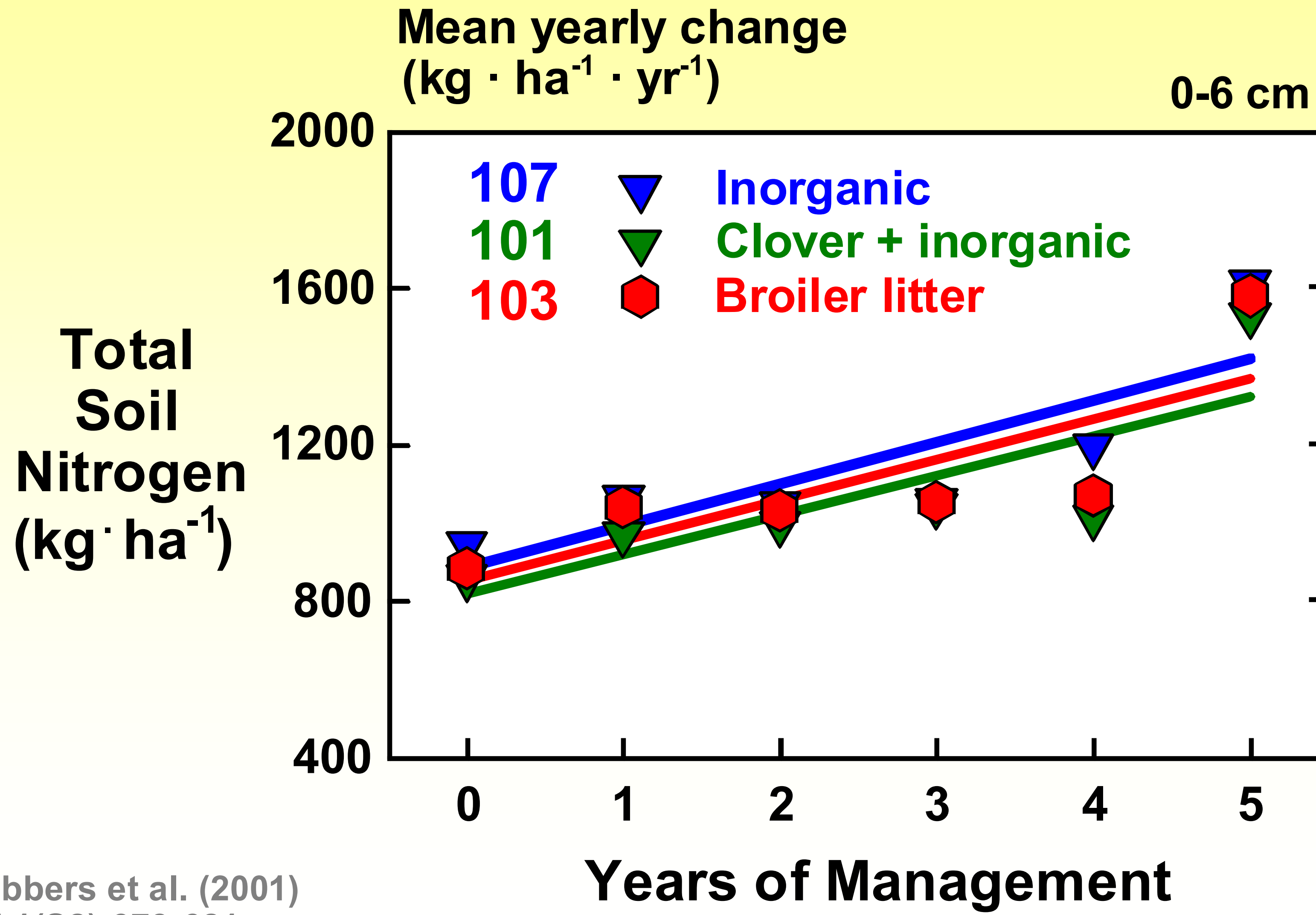
Salem Road Grazing Study
Fertilization Source Effect



Impact
Fertilizer sources were equally effective in sequestering soil organic C

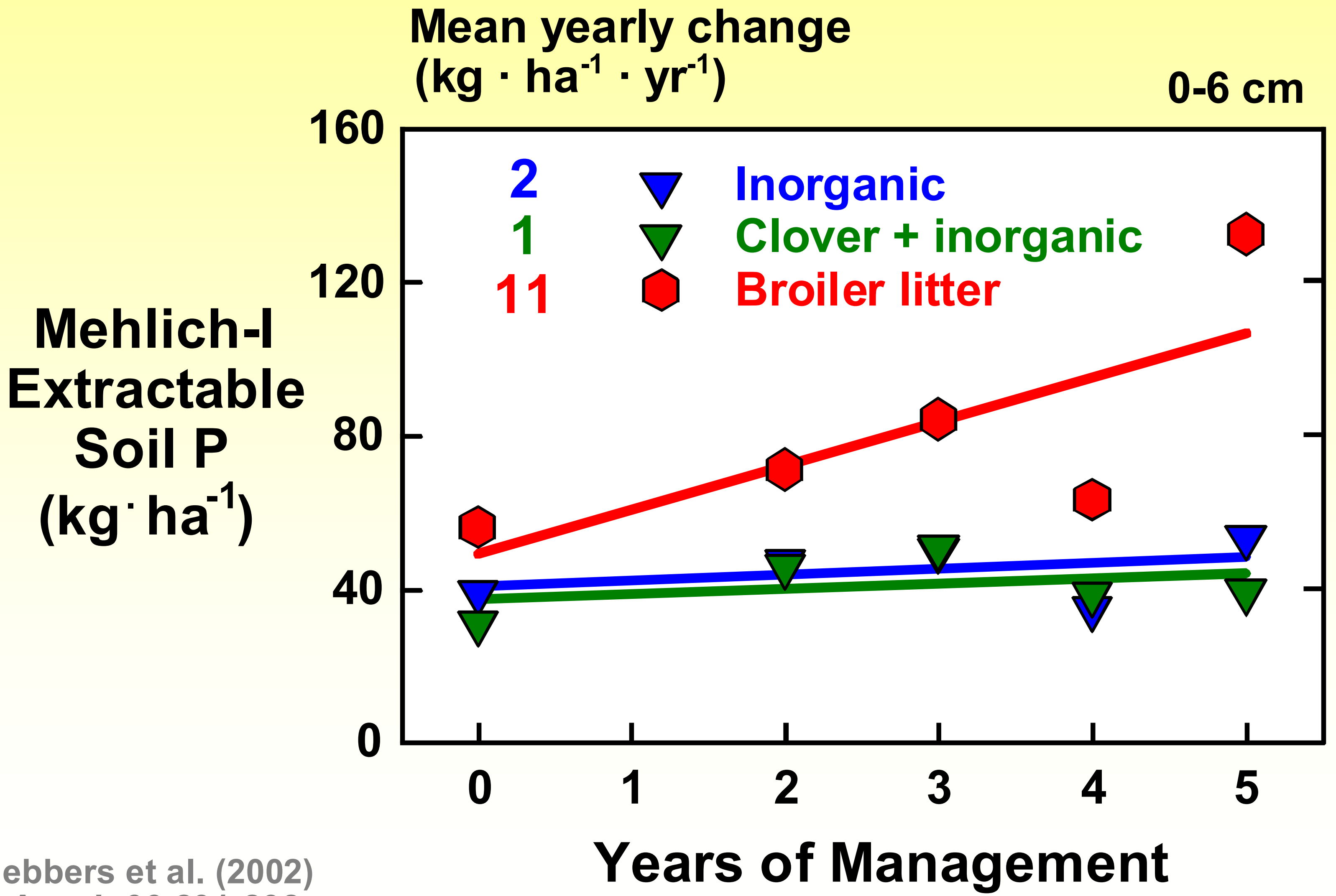
Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65: 834-841.

Salem Road Grazing Study
Fertilization Source Effect



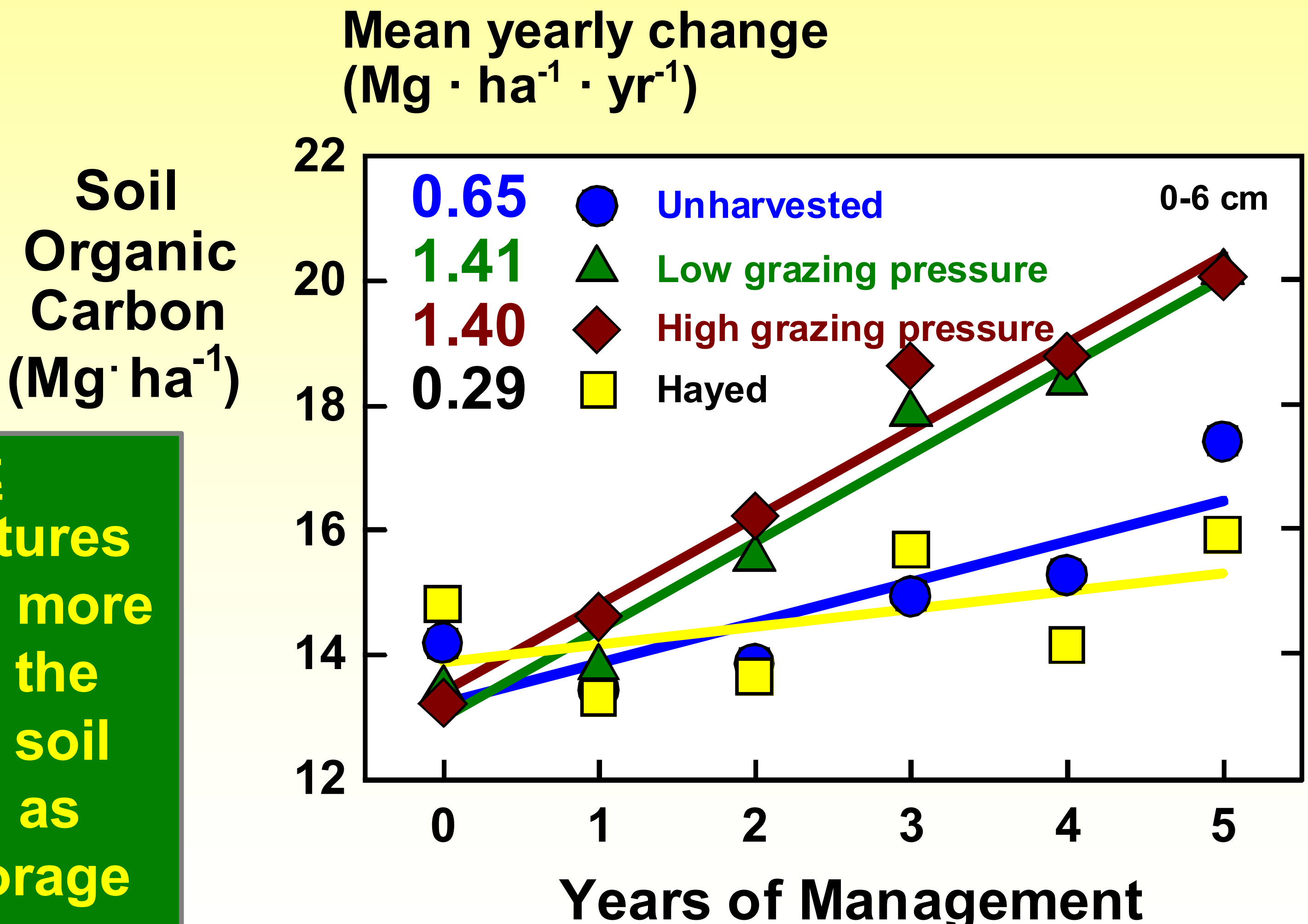
From Franzluebbers et al. (2001)
The Sci. World 1(S2):673-681.

Salem Road Grazing Study
Fertilization Source Effect



From Franzluebbers et al. (2002)
Soil Sci. Soc. Am. J. 66:291-298.

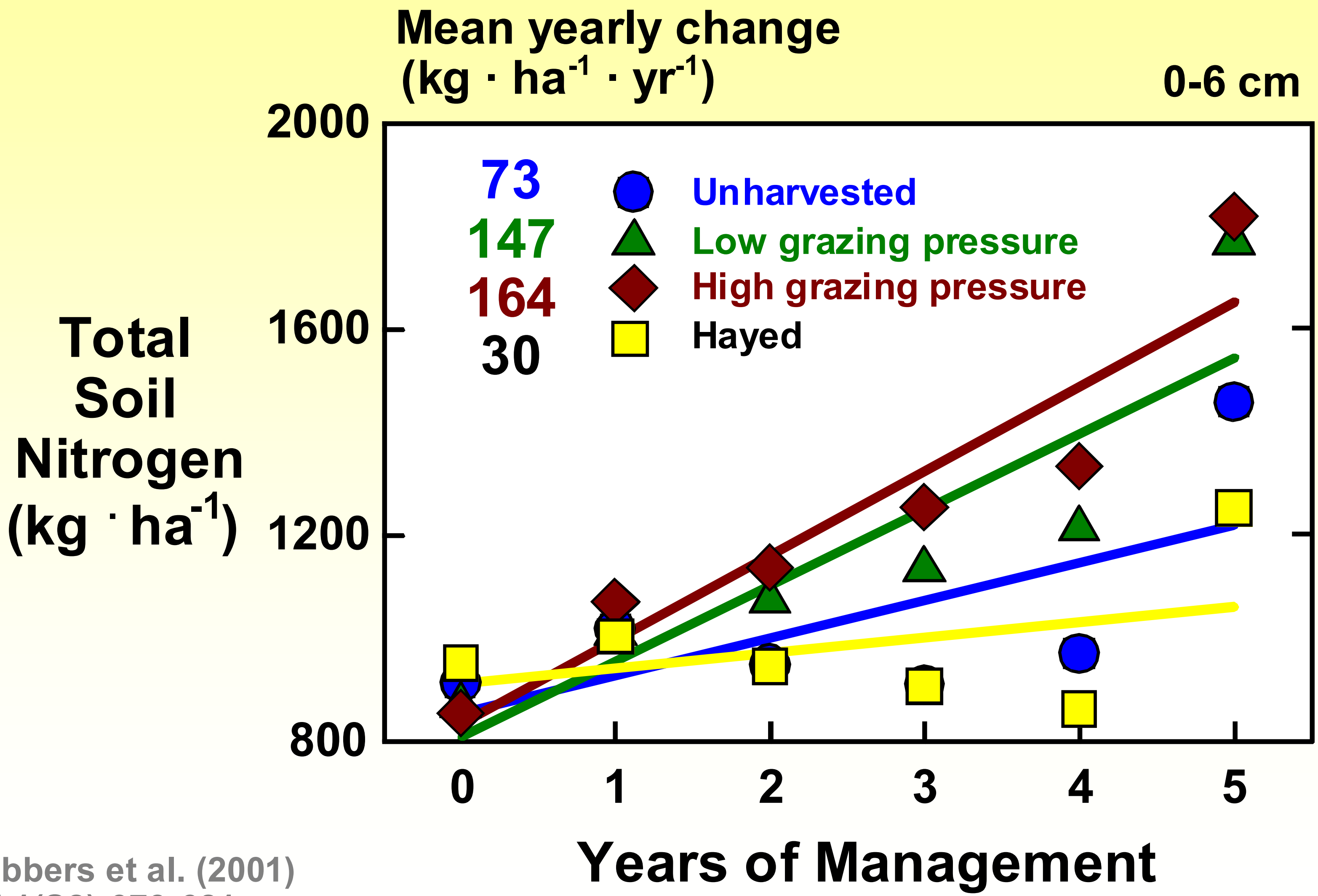
Salem Road Grazing Study
Harvest Strategy Effect



Impact
Grazed pastures sequestered more than twice the quantity of soil organic C as ungrazed forage systems.

Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65: 834-841.

Salem Road Grazing Study
Harvest Strategy Effect



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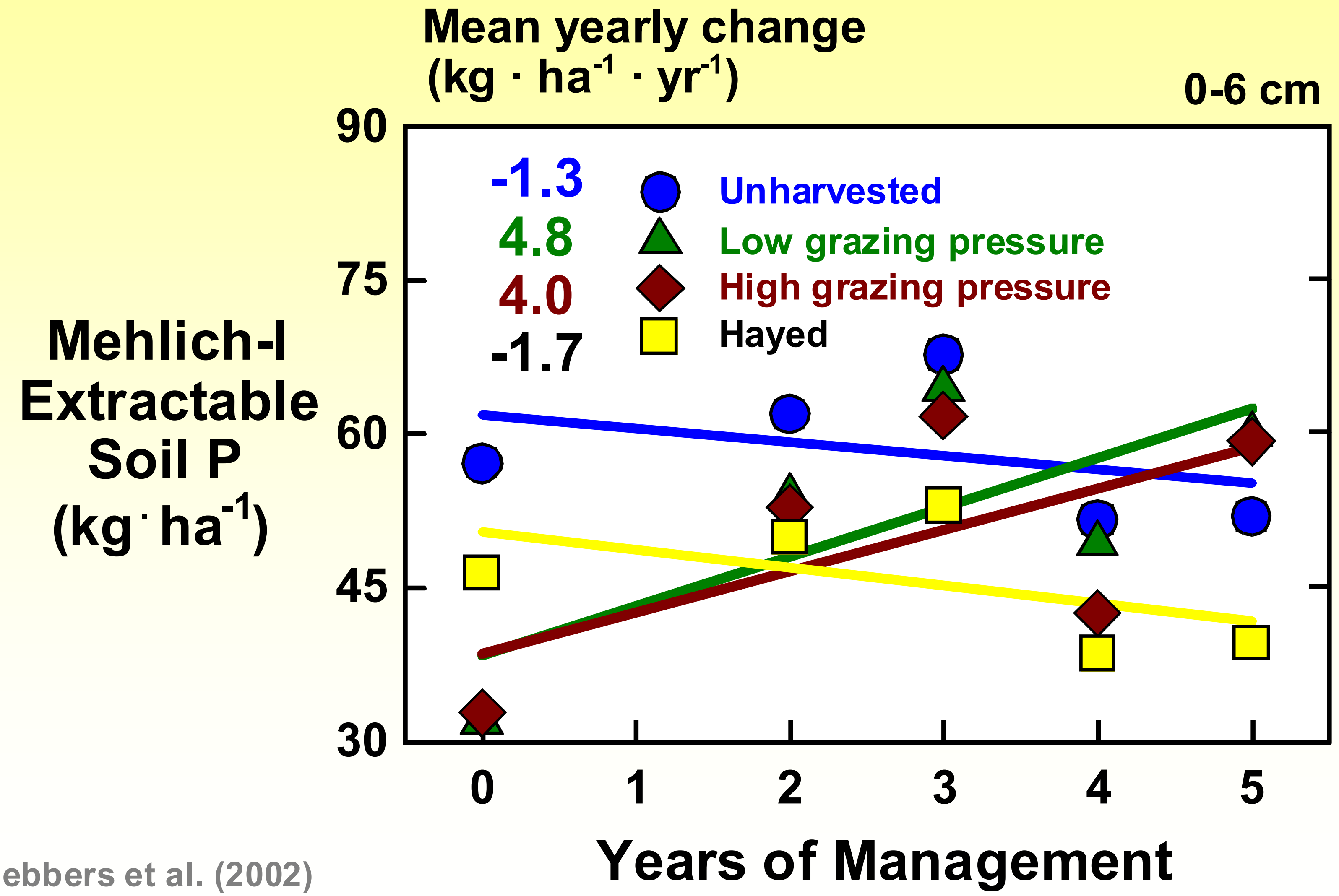
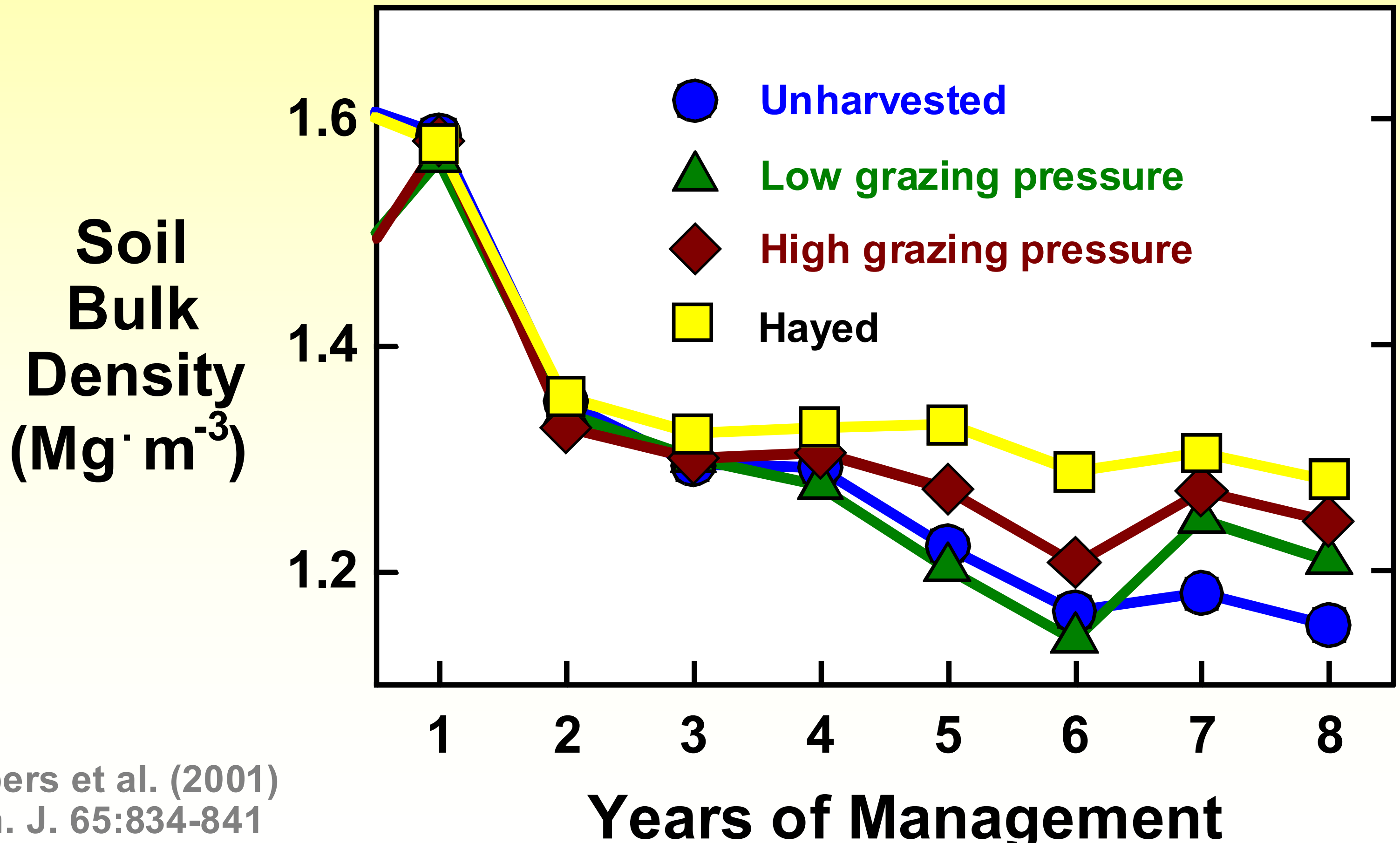
Salem Road Grazing Study

Harvest Strategy Effect



From Franzluebbers et al. (2002)
Soil Sci. Soc. Am. J. 66:291-298.

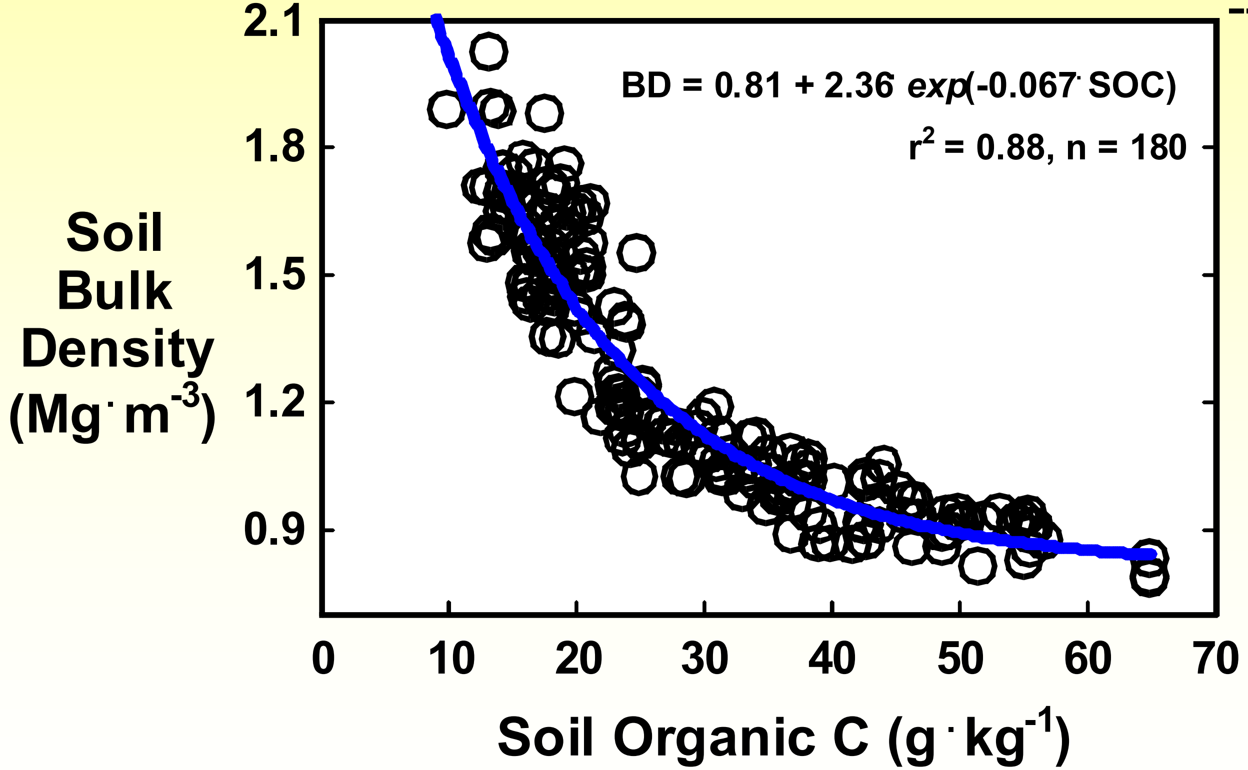
Salem Road Grazing Study
Harvest Strategy Effect



From Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841 and unpublished data.

Salem Road Grazing Study

Relationship between soil bulk density and soil organic C of 0- to 2-cm depth during first five years



Water (cm) held at saturation capacity to a depth of 20 cm

6.4

8.7

10.9

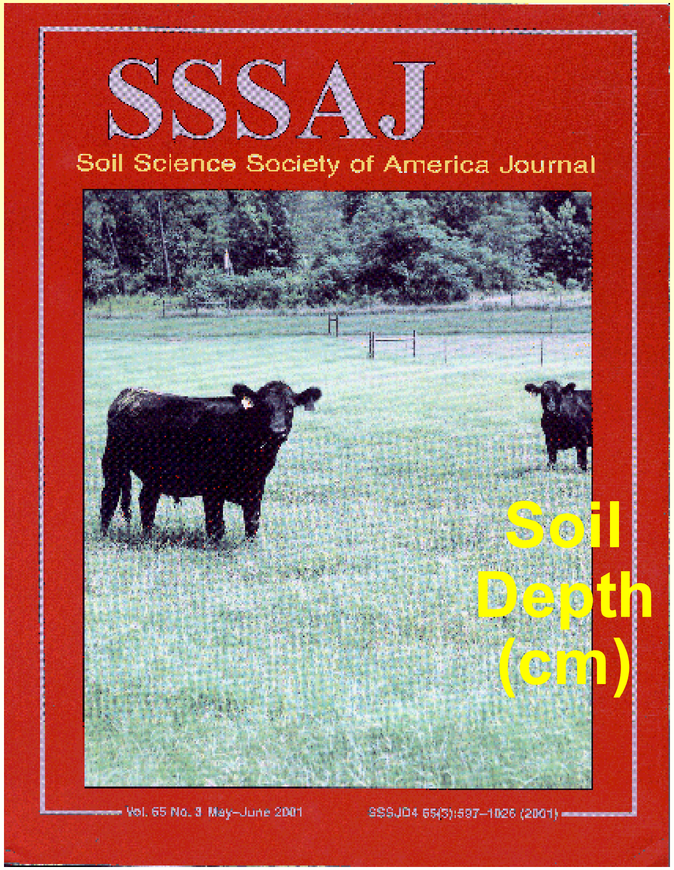
13.2

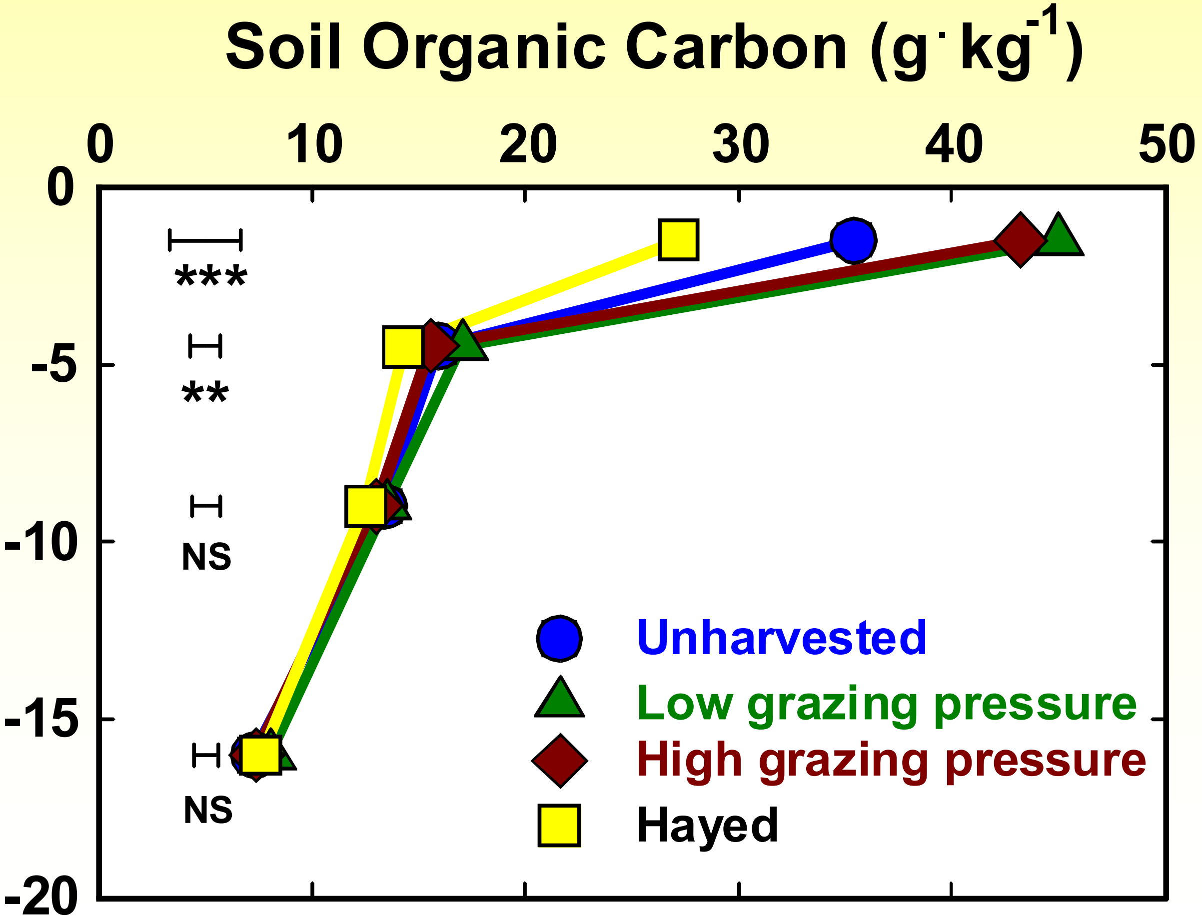
From Franzluebbers et al. (2001)
Soil Sci. Soc. Am. J. 65:834-841

Salem Road Grazing Study

Harvest Strategy Effect

Vertical distribution of soil organic C





From Franzluebbers et al. (2001)
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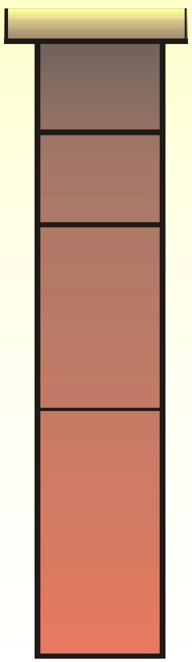
Salem Road Grazing Study
Harvest Strategy Effect

Vertical distribution of organic C



Carbon stock ($Mg \cdot ha^{-1}$)

	Unharvested	Low grazing pressure	High grazing pressure	Hayed
Surface residue	**2.5** a	**2.1** b	**1.5** c	**0.9** d
0-3 cm	**10.6** b	**12.7** a	**13.0** a	**9.6** c
3-6 cm	**6.8** ab	**7.4** a	**7.1** a	**6.3** b
6-12 cm	**12.3** a	**12.6** a	**12.2** a	**11.7** a
12-20 cm	**9.2** a	**10.1** a	**9.2** a	**9.7** a
	41.4 b	**44.9** a	**42.9** ab	**38.1** c

From Franzluebbers et al. (2001)
Soil Sci. Soc. Am. J. 65:834-841

Salem Road Grazing Study

Fate of N in management systems

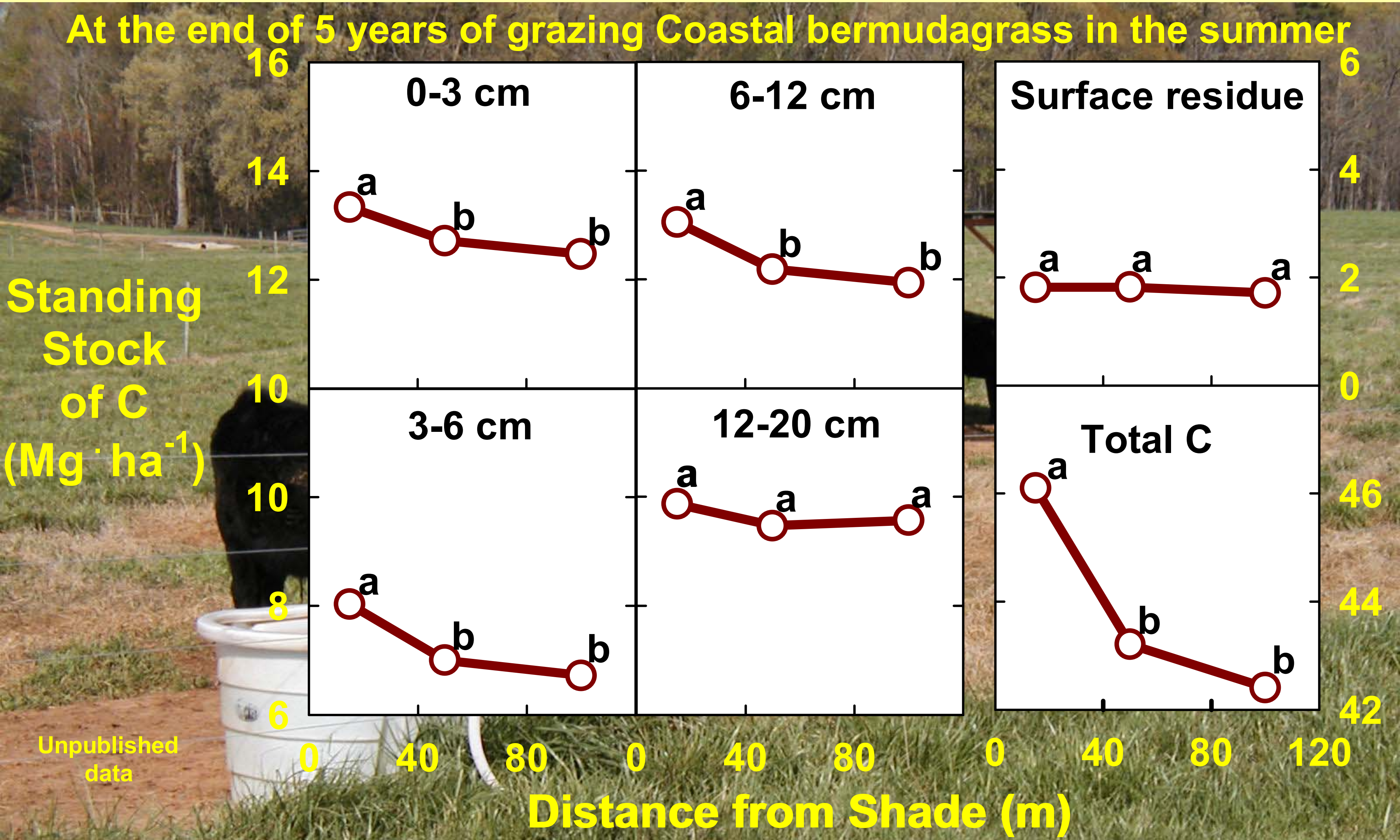
Of the average N applied in these systems (214 kg N · ha^{-1} · yr^{-1}), the following budget could be constructed:

System	Residue	Soil 0-6 cm	Soil 6-20 cm	Hay	Animal gain	Total
		% of applied N				
Unharvested	12	3	20	0	0	35
Low grazing pressure	10	32	31	0	3	76
High grazing pressure	8	48	23	0	3	82
Hayed	4	-5	12	57	0	68

From Franzluebbers et al. (2001) The Sci. World 1(S2):673-681.

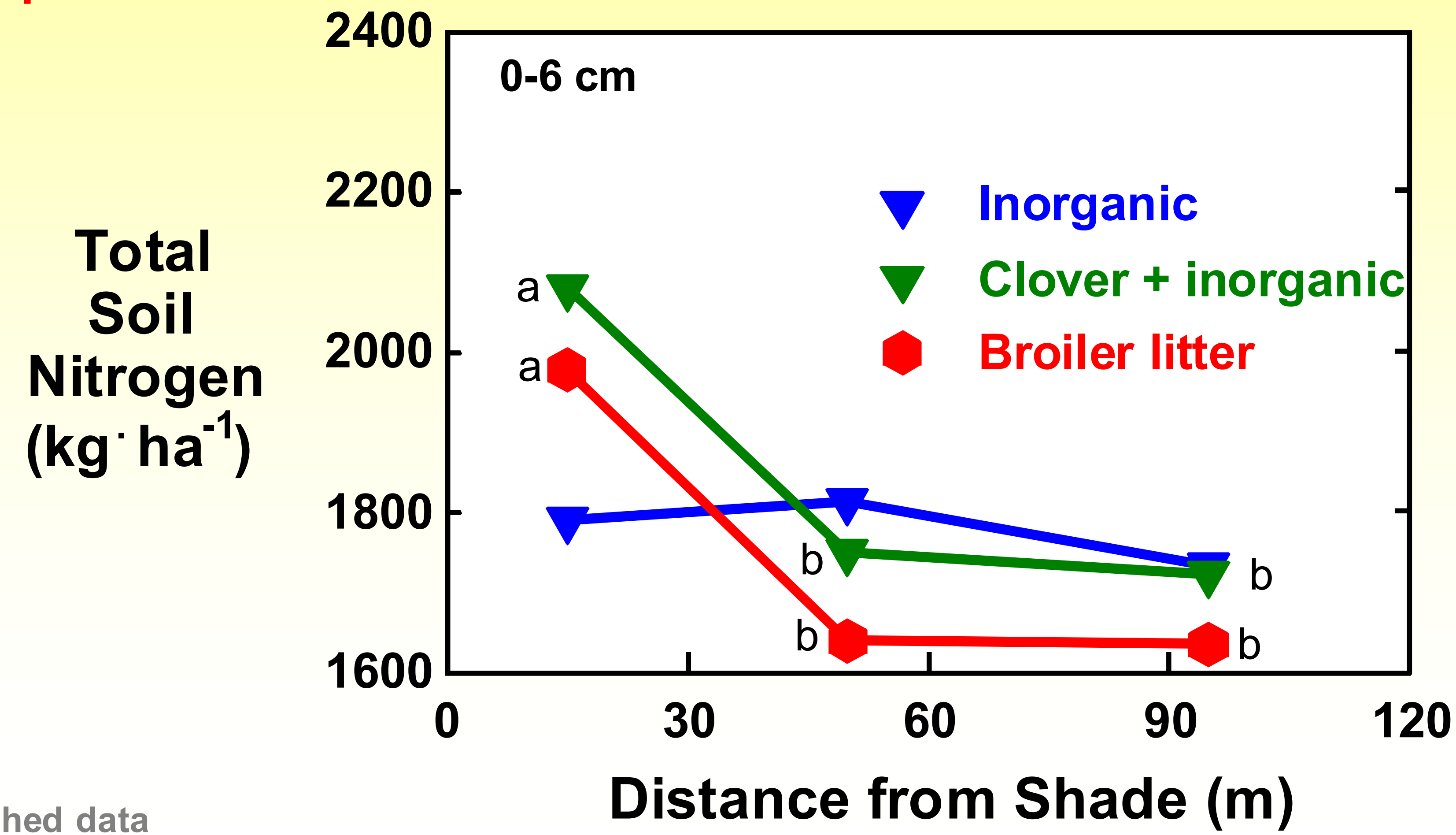
Salem Road Grazing Study

Spatial Distribution within Paddocks



Salem Road Grazing Study

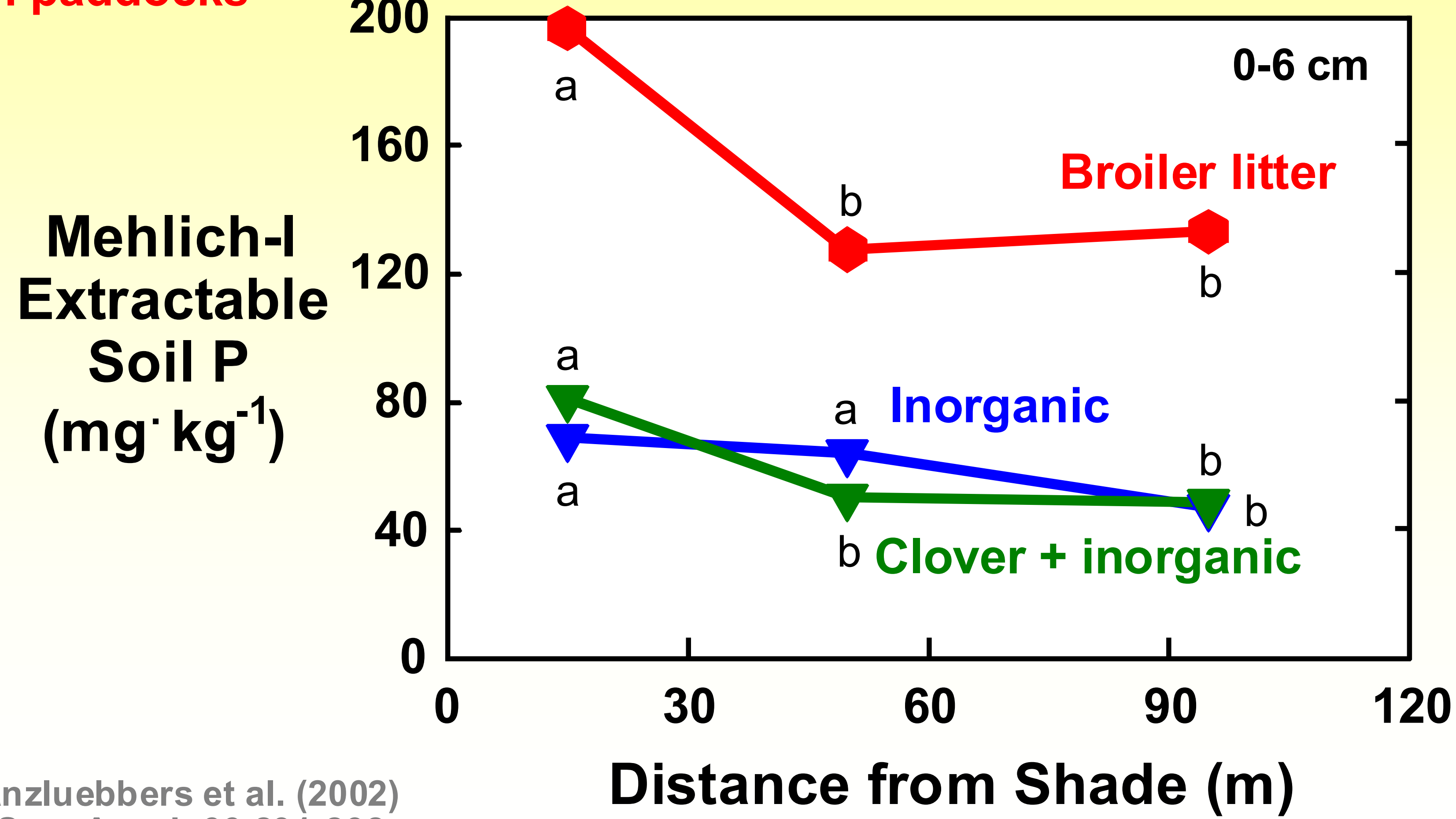
Spatial distribution of total soil N within paddocks



Unpublished data

Salem Road Grazing Study

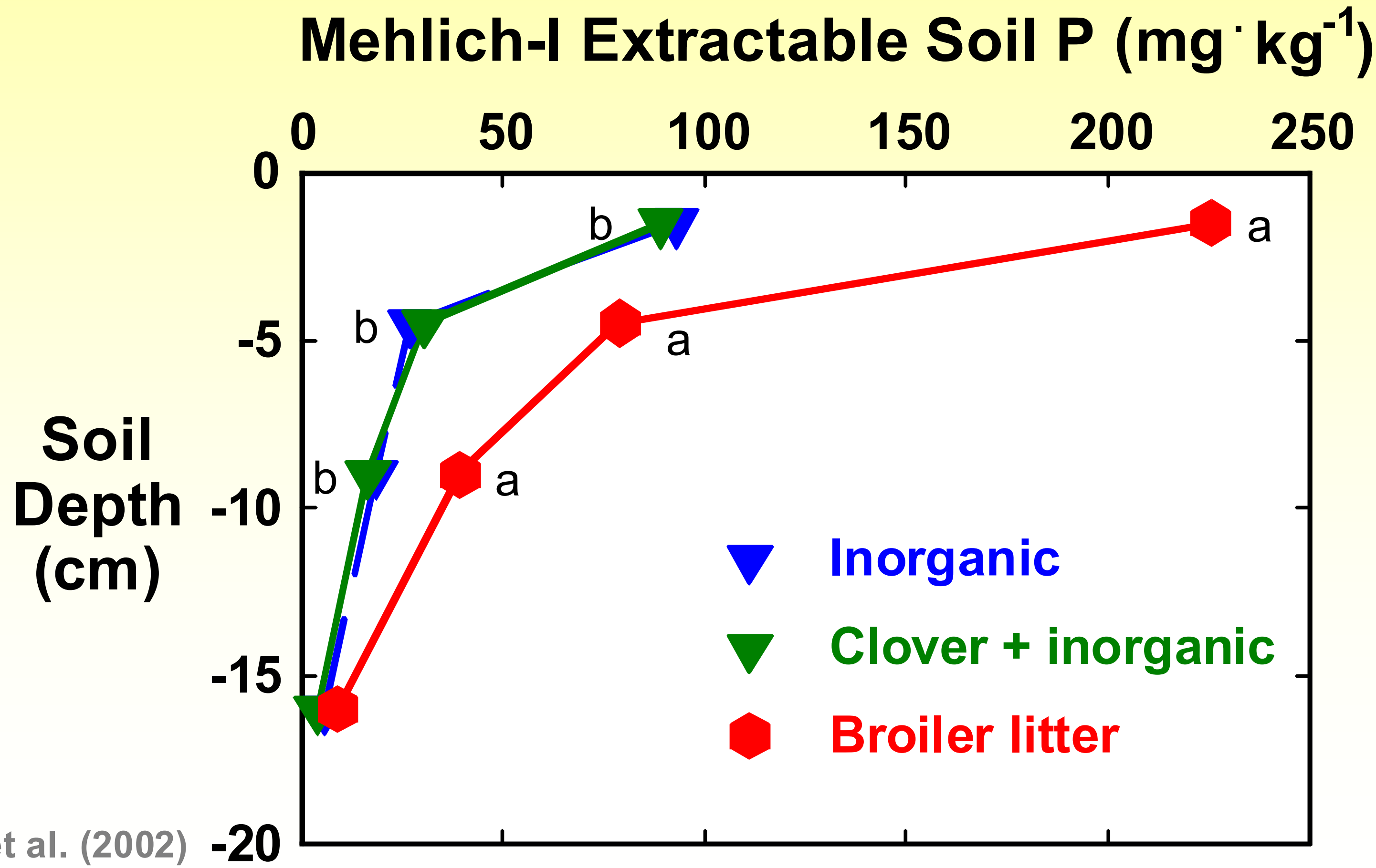
Spatial distribution of extractable soil P within paddocks



From Franzluebbers et al. (2002) Soil Sci. Soc. Am. J. 66:291-298.

Salem Road Grazing Study

Vertical distribution of extractable soil P with depth



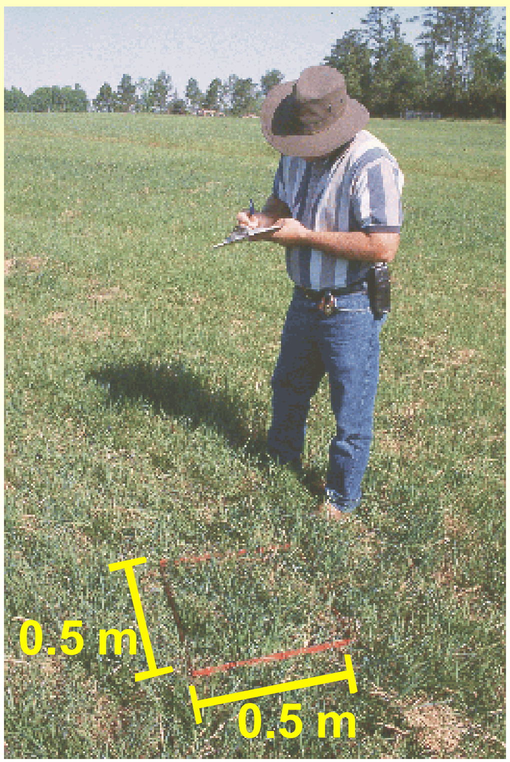
From Franzluebbers et al. (2002) Soil Sci. Soc. Am. J. 66:291-298.

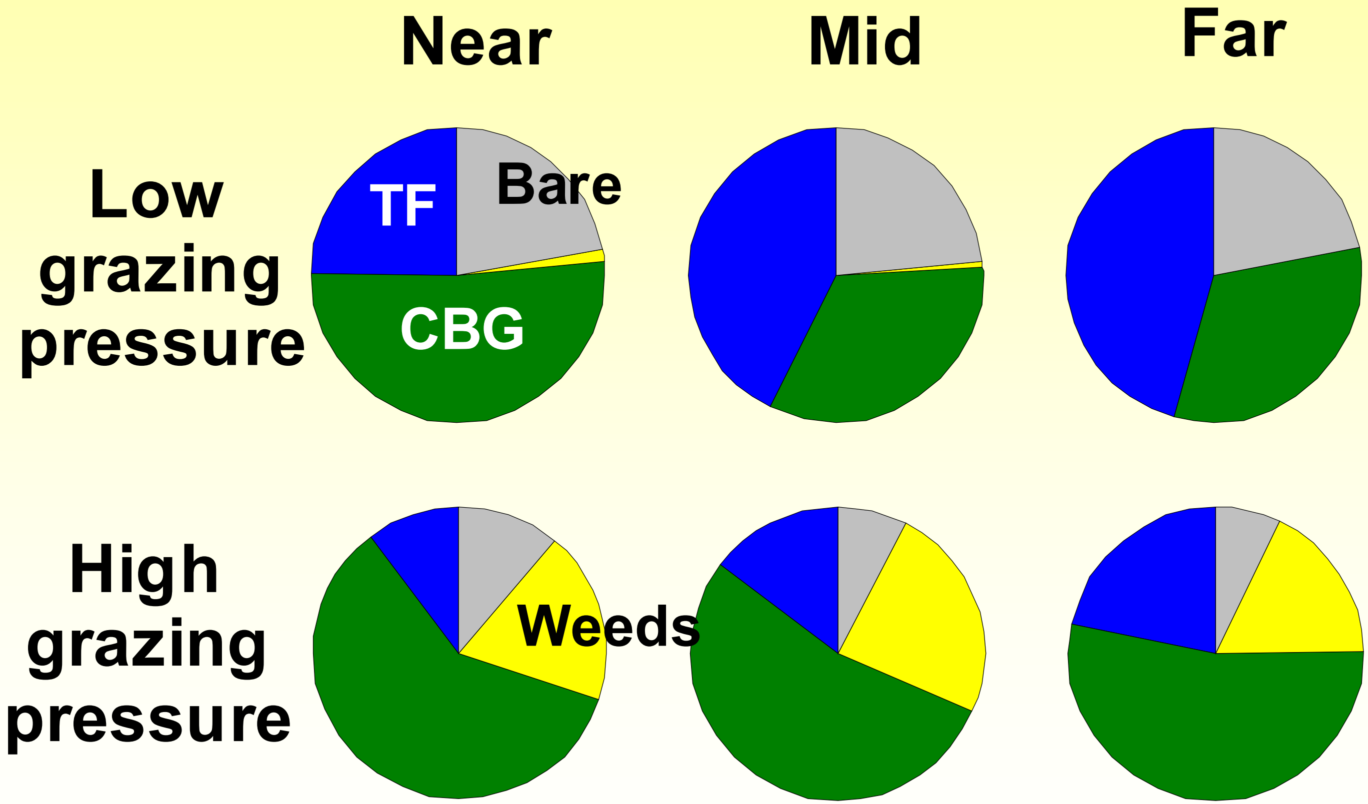
Salem Road Grazing Study

Variation in ground cover

Distance from Shade / Water

May 2001





Unpublished data

TF - tall fescue, CBG - ‘Coastal’ bermudagrass

Salem Road Grazing Study

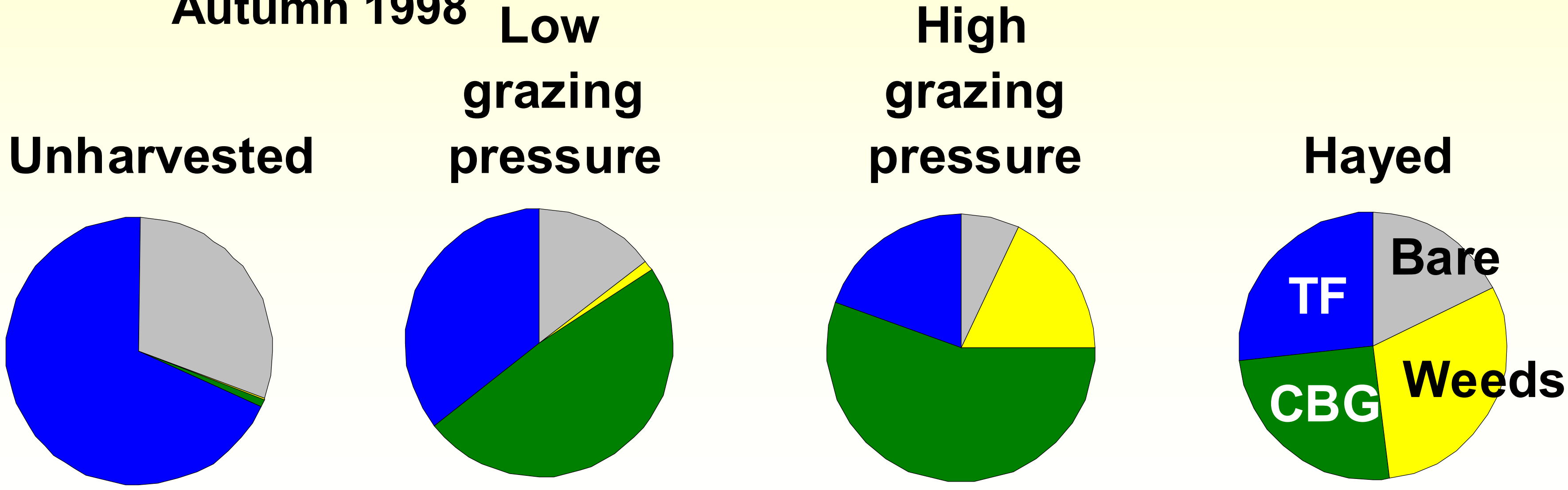
Variation in ground cover
due to harvest strategy

Evaluated May 2001
following interseeding
of tall fescue into
bermudagrass in
Autumn 1998

Planted grasses

TF = Tall fescue

CBG = Coastal bermudagrass



Unpublished data

Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Fertilization strategy resulted in:

- Equal changes in soil organic C ($\sim$0.9 $Mg \cdot ha^{-1} \cdot yr^{-1}$)
- Equal changes in total soil N (104 $kg \cdot ha^{-1} \cdot yr^{-1}$)
- Greater change in extractable soil P with broiler litter (11 $kg \cdot ha^{-1} \cdot yr^{-1}$) than with inorganic or clover + inorganic fertilization (1 $kg \cdot ha^{-1} \cdot yr^{-1}$)

Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Harvest strategy resulted in:

- Greater change in soil organic C with grazing (1.4 $Mg \cdot ha^{-1} \cdot yr^{-1}$) compared with haying (0.3 $Mg \cdot ha^{-1} \cdot yr^{-1}$) and unharvested management (0.7 $Mg \cdot ha^{-1} \cdot yr^{-1}$)
- Greater change in total soil N with grazing (156 $kg \cdot ha^{-1} \cdot yr^{-1}$) compared with haying (30 $kg \cdot ha^{-1} \cdot yr^{-1}$) and unharvested management (73 $kg \cdot ha^{-1} \cdot yr^{-1}$)
- Greater change in extractable soil P with grazing (4.4 $kg \cdot ha^{-1} \cdot yr^{-1}$) compared with haying and unharvested (–1.5 $kg \cdot ha^{-1} \cdot yr^{-1}$)
- Few differences in soil properties, including compaction, between low and high grazing pressure variables

Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Soil properties became spatially variable:

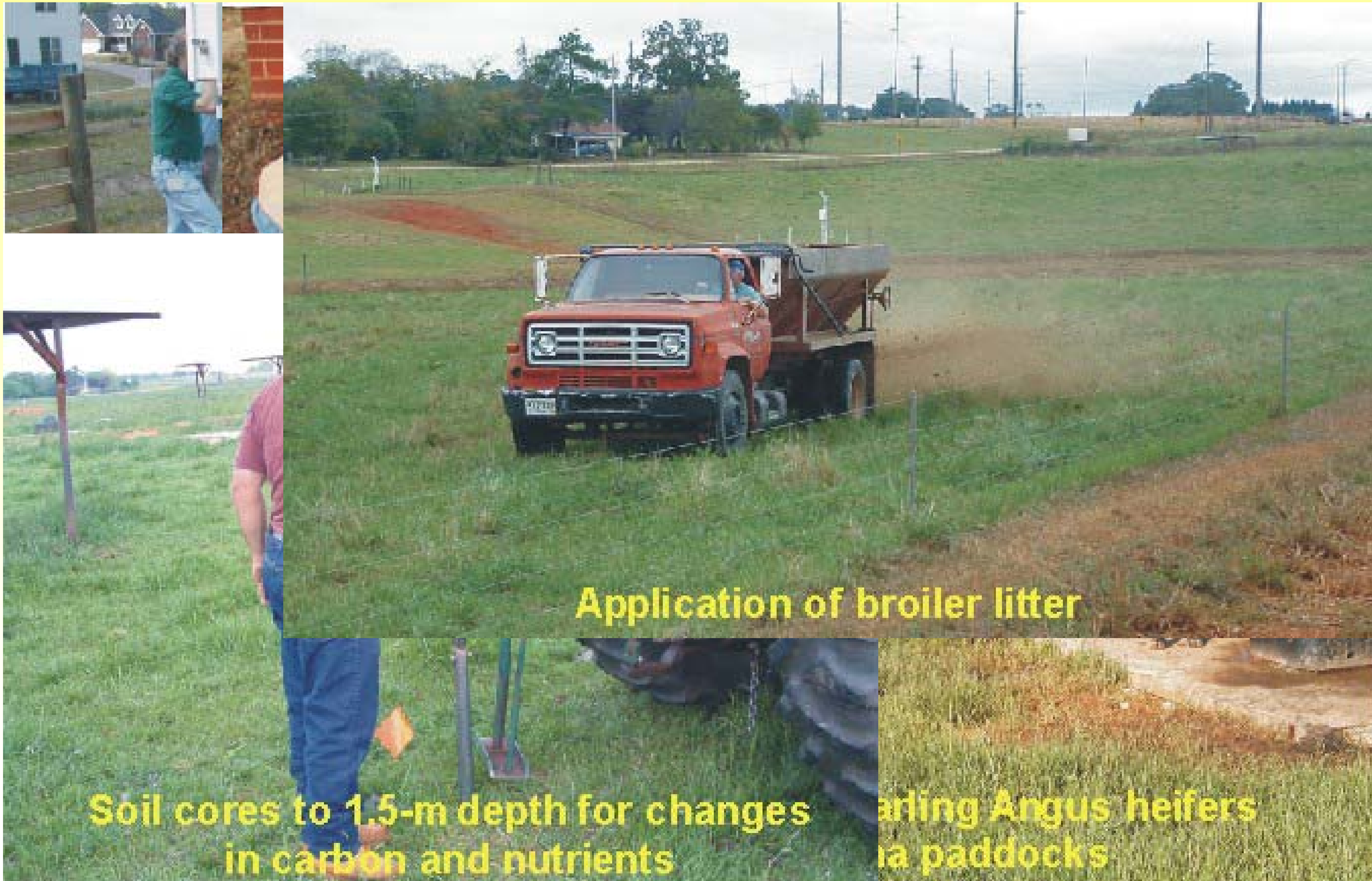
- ***By depth***, **where concentrations of nutrients accumulated near the soil surface, especially within the surface 6 cm**

- ***Due to animal behavior***, **where nutrients accumulated near shade and water sources as a result of more time spent at these locations**

On-Going Studies in Watkinsville GA

- ✓ Dawson Field grazing study, Watkinsville, Hog Mountain Rd
- ✓ 2002-2004, 'Jesup' tall fescue
- ✓ 3 endophyte associations
  - Wild-type endophyte
  - Max-Q endophyte (low ergot alkaloid)
  - No endophyte
- ✓ 2 fertilization regimes (180 kg N ha^{-1} yr^{-1})
  - Inorganic
  - Broiler litter
- ✓ 2 replications
- ✓ +2 hayed, Max-Q, inorganically fertilized pastures

Dawson Field Grazing Study

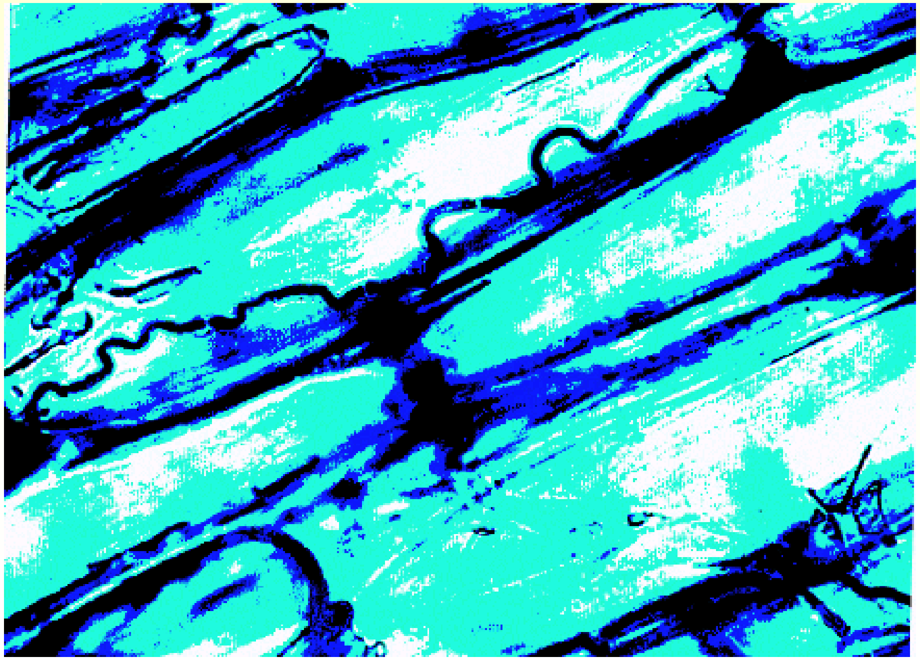


Dawson Field Grazing Study

What is the tall fescue-endophyte association?

- ✓ **The fungus, *Neotyphodium coenophialum*, growing within the herbage of tall fescue, *Festuca arundinacea*.**
- ✓ **A mutualistic relationship, whereby the fungus receives:**
  - **energy**
  - **nutrients**
  - **shelter**
  - **means of propagation**
- ✓ **And the fungus provides the plant with:**
  - **various alkaloids: N-containing ring structures that deter insects and overgrazing**
  - **drought tolerance**
  - **persistence**

“Endo” living within, “phyte” plant



Dawson Field Grazing Study

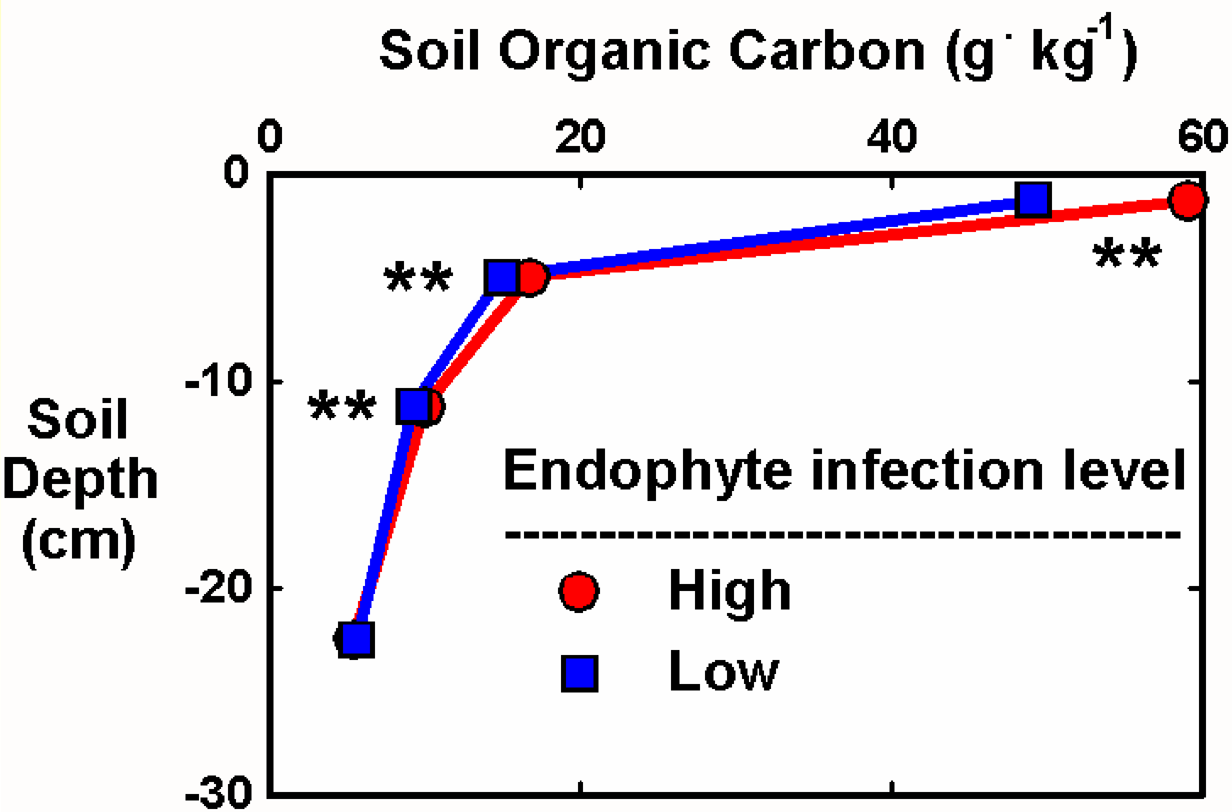
Why study the tall fescue-endophyte association?

- ✓ Tall fescue is still the most widely adapted, cool-season perennial forage in the southeastern USA.
- ✓ Farm animals grazing endophyte-infected tall fescue variably develop animal health disorders (fescue foot, fat necrosis, fescue toxicosis). Strategies to overcoming these disorders have not been universally understood by scientists, developed by industry, nor accepted by producers.
- ✓ Two important developments have prompted our current investigations:
  - ✓ "Novel" endophytes that do not produce ergot alkaloids (responsible for fescue toxicosis) have been identified and placed into improved plant cultivars.
  - ✓ Soil carbon sequestration under endophyte-infected was found greater than under uninfected tall fescue.

Dawson Field Grazing Study

✓ **Previous research illustrated that soil organic C accumulated in response to endophyte**

-From Franzluebbers et al. (1999) Soil Sci. Soc. Am. J. 63:1687-1694



Specific mineralization of SOC ($mg\ CO_2\text{-}C\ g^{-1}\ SOC$) Low		High
98	**	78
43	**	38
26	*	23
16		16

Dawson Field Grazing Study

14 paddocks (2.5 acre each) established as individual water catchments in 2002
- 12 grazed + 2 hayed

3 tall fescue-endophyte associations
- ‘Jesup’ endophyte-free (**E-Free**)
- ‘Jesup’ Max Q endophyte (**E-MaxQ**)
- ‘Jesup’ wild endophyte (**E-Wild**)

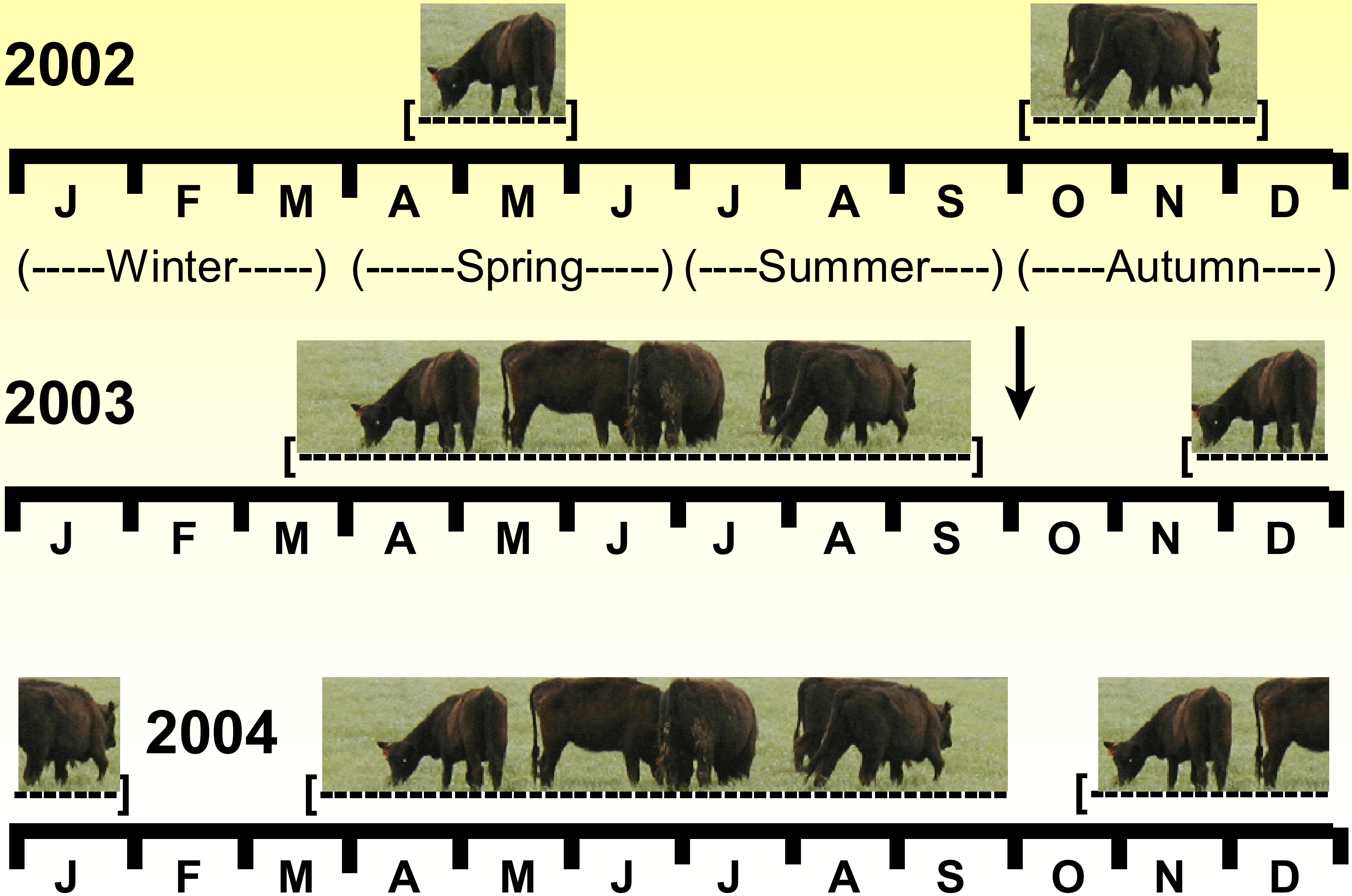
2 fertilization regimes (80 lb N/a, 2x/yr)
- inorganic
- broiler litter

2 reps

Grazed by yearling Angus heifers

Dawson Field Grazing Study

Time of grazing



Dawson Field Grazing Study

Season	Days with grazing (%)	Average daily gain (kg · d^{-1})				
		E-Free		E-MaxQ		E-Wild
Winter (Jan-Mar)	26	1.13		1.21	>	0.88
Spring (Apr-Jun)	79	0.90		0.88	>	0.55
Summer (Jul-Sep)	61	0.64		0.66		0.56
Autumn (Oct-Dec)	76	0.69	<	0.80	>	0.52
Yearly	60	0.84	<	0.89	>	0.64

Dawson Field Grazing Study

Season	Stocking rate (head · ha^{-1})	Live-weight gain (kg · ha^{-1}) E-Free	E-MaxQ		E-Wild
Winter (Jan-Mar)	1.1	97	110		98
Spring (Apr-Jun)	3.3	254	252	>	206
Summer (Jul-Sep)	2.1	103	104	<	129
Autumn (Oct-Dec)	3.3	222	248	>	188
Yearly	2.4	676	714	>	622

Dawson Field Grazing Study

Previous research:

Field sampling of tall fescue paddocks at the end of 20 years

	Low Fertilizer		High Fertilizer		
Soil component	E-	E+	E-		E+
	------------ Mg SOC · ha^{-1} ------------				
Whole soil	37.2	38.0	38.7	*	42.0
Large macroaggregates	26.9	29.6	30.5		30.4
Small macroaggregates	14.7	14.8	14.7	*	16.7
Microaggregates	3.4	3.3	3.3		3.6

Franzluebbers and Stuedemann (2005) Soil Sci. Soc. Am. J. 69:396-403

Dawson Field Grazing Study

Previous research:

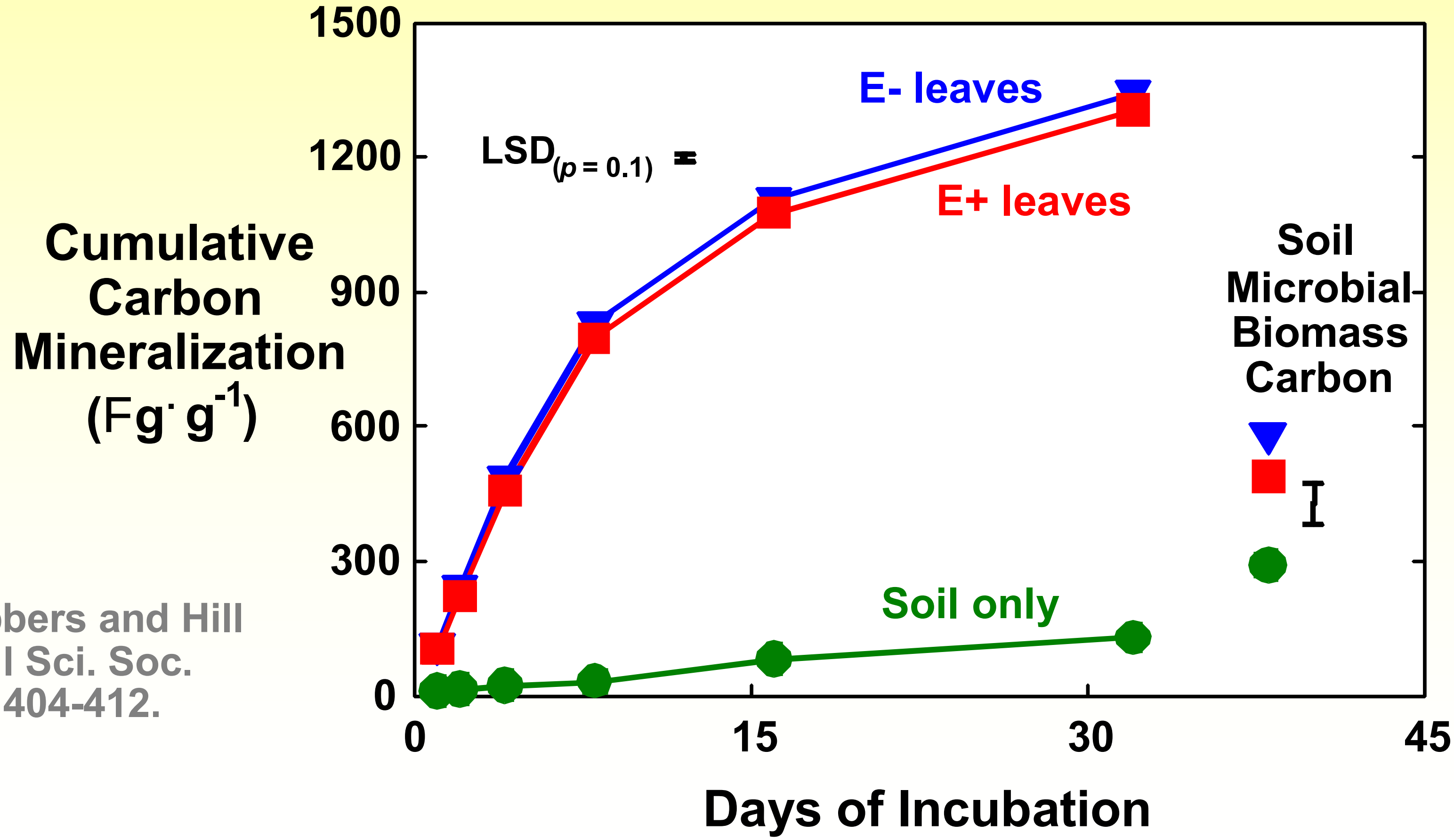
Biologically active pools of soil C and N in long-term field study

	Low Fertilizer			High Fertilizer	
Soil component	E-	E+	E-		E+
	---------- mg C pool · g SOC^{-1} ----------				
Particulate (>0.05 mm)	410	390	430	*	400
Microbial biomass	44	45	45	**	39
Mineralizable	44	45	43	*	38
	---------- mg N pool · g TSN^{-1} ----------				
Particulate (>0.05 mm)	660	580	620		560
Mineralizable	43	41	44	*	39

Franzluebbers and Stuedemann (2005) Soil Sci. Soc. Am. J. 69:396-403

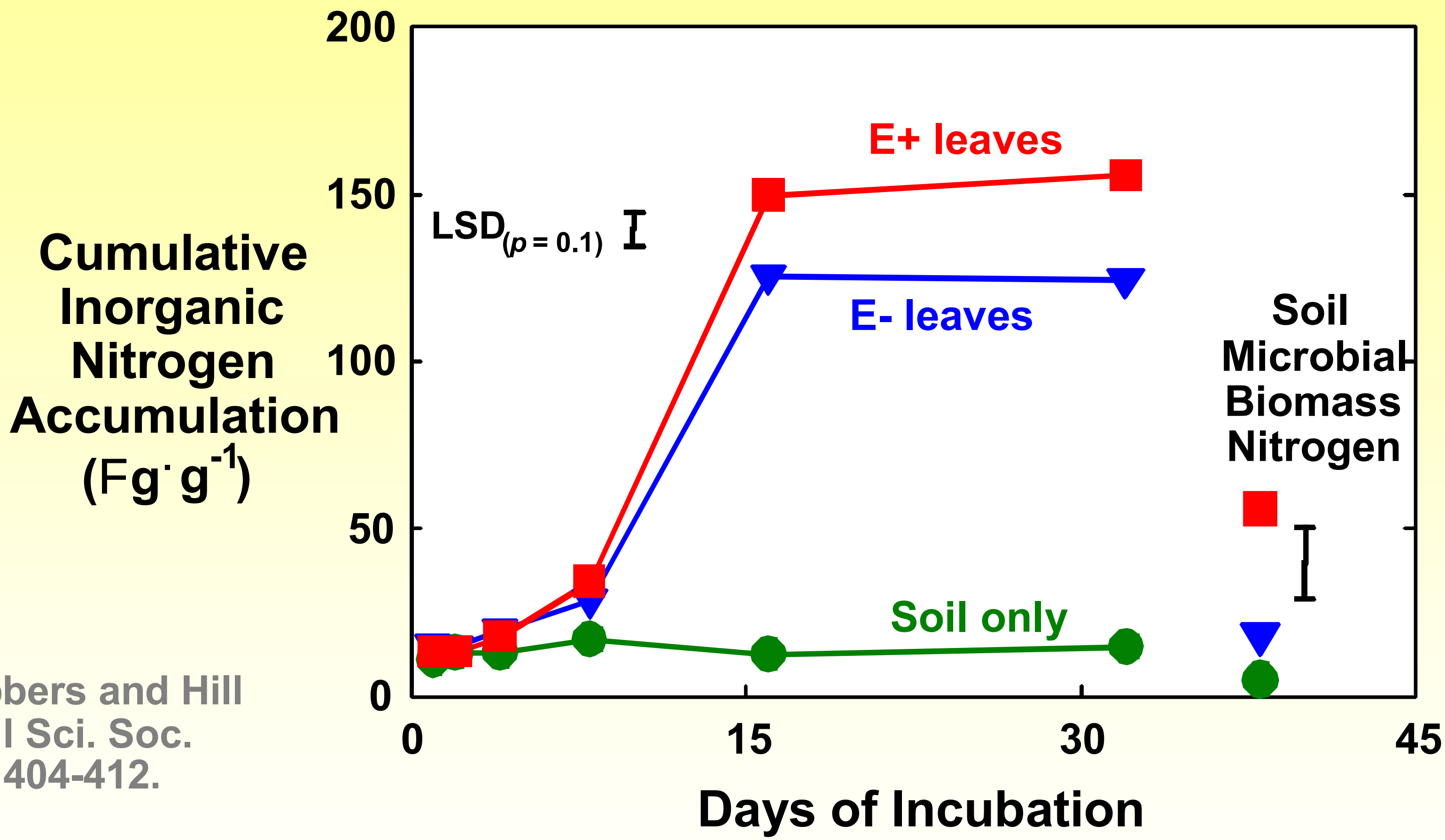
Dawson Field Grazing Study

To directly test whether soil microbial activity might be inhibited by compounds in the tall fescue-endophyte association, a laboratory decomposition study was performed with leaves from E- and E+ pastures.



Franzluebbers and Hill (2005) Soil Sci. Soc. Am. J. 69:404-412.

Dawson Field Grazing Study

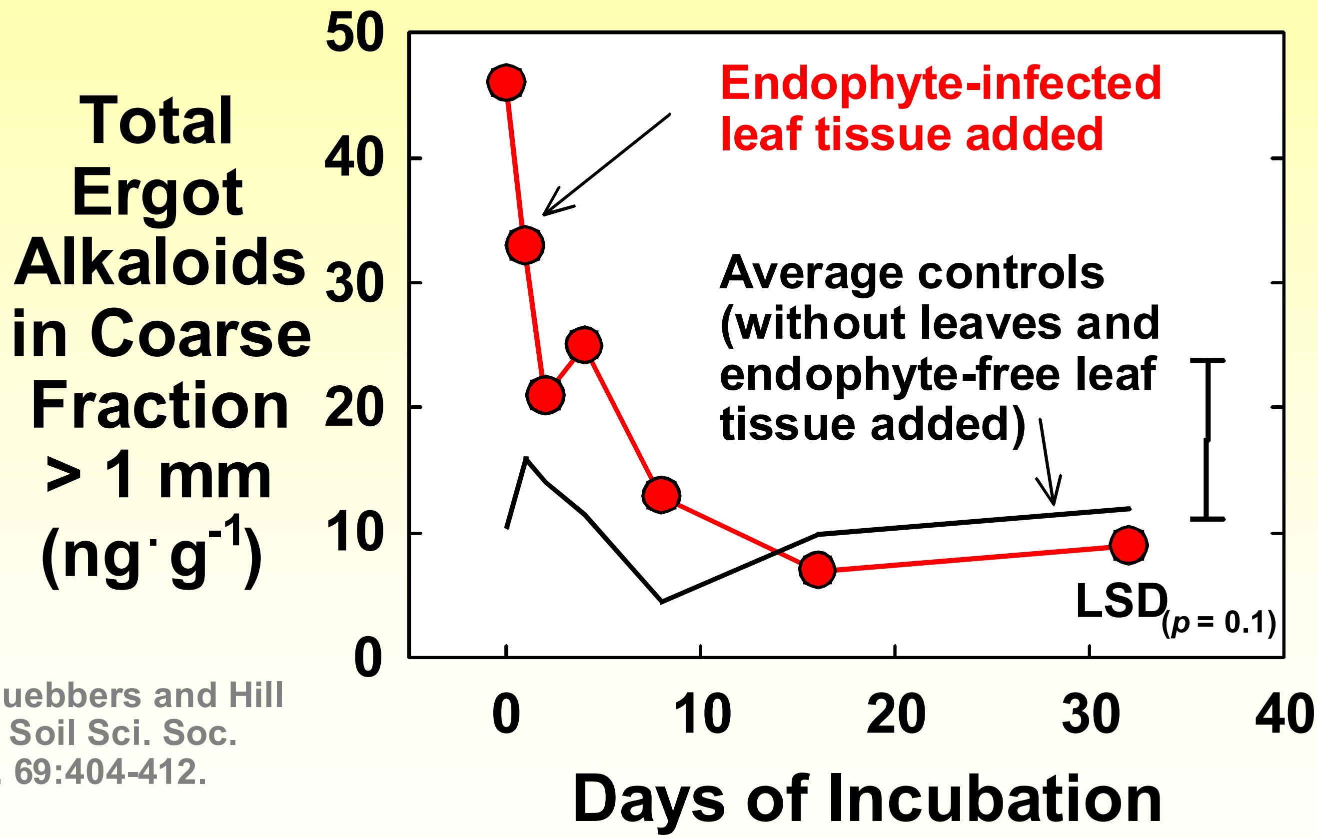


Franzluebbers and Hill (2005) Soil Sci. Soc. Am. J. 69:404-412.

Although biologically active soil C pools were negatively affected by endophyte infection as observed in sampling of field soils, biologically active soil N pools were enhanced with endophyte infection.

Dawson Field Grazing Study

Fate of ergot alkaloids added during incubation with soil.



Franzluebbers and Hill (2005) Soil Sci. Soc. Am. J. 69:404-412.

Decomposition of ergot alkaloids in tall fescue leaves incubated with soil was rapid.

Dawson Field Grazing Study

If ergot alkaloids decomposed so rapidly during short-term incubation, soil exposed to long-term management of E+ tall fescue would probably not have evidence of ergot alkaloids.

Soil fraction	E-		E+
	-------- ηg · g^{-1} soil --------		
Soil sediment	12	*	28
Coarse fraction	2.2	*	5.8
Water extract	0.22	*	0.27

Franzluebbers and Hill (2004) Soil Sci. Soc. Am. J. (in review)

Discovery of significant "background" ergot alkaloid concentration in soil under 10-year-old pasture suggests that other environmental consequences of wild-type endophyte infection could occur, possibly in water runoff.

Dawson Field Grazing Study

A next step – Constituents in water runoff (nutrients, bacteria, ergot alkaloids...)

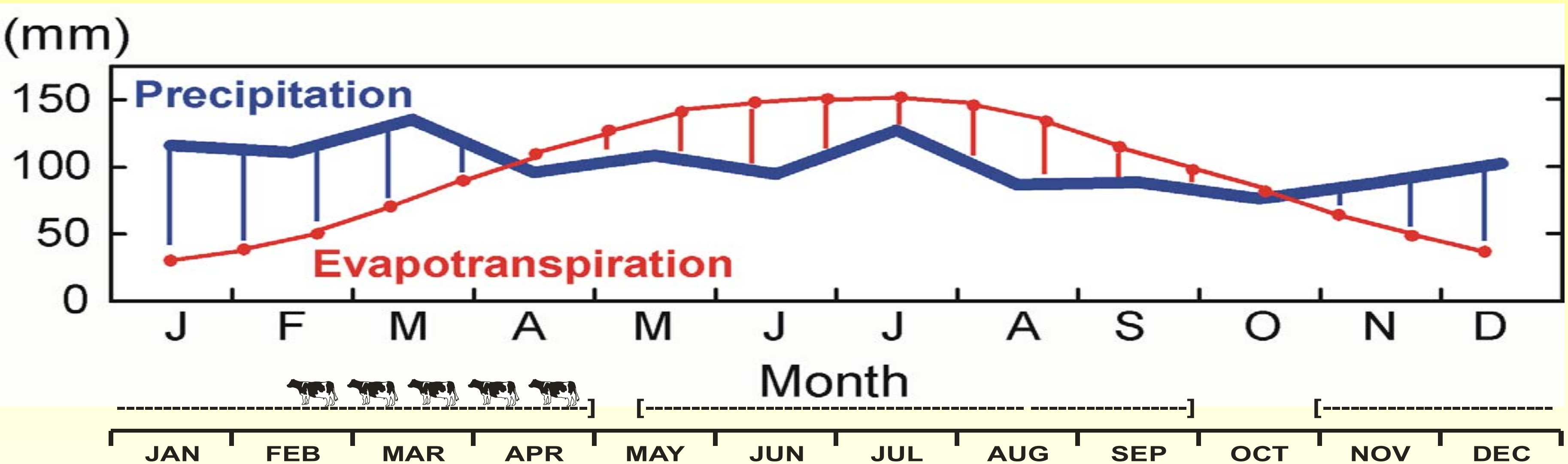
On-Going Studies in Watkinsville GA

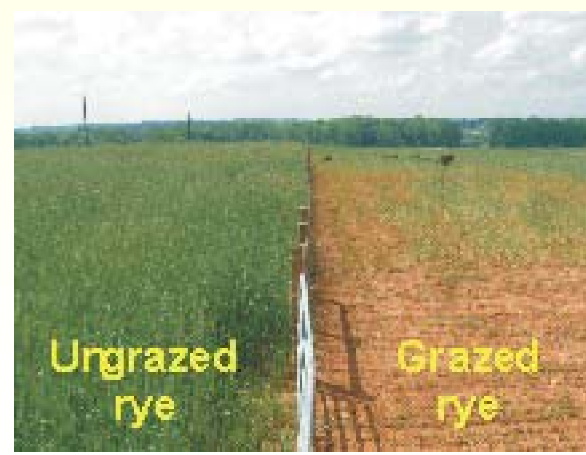
- ✓ Pasture-Crop Rotation study, Watkinsville, Govt. Station Rd.
- ✓ 1982-2002, tall fescue-endophyte associations
- ✓ 2002-2004, grain cropping with cover crops
- ✓ 2 cropping systems
  - Summer grain – winter cover crop (sorghum-rye)
  - Winter grain – summer cover crop (wheat – pearl millet)
- ✓ 2 tillage regimes
  - Conventional tillage
  - No tillage
- ✓ 2 cover crop management regimes
  - Unutilized
  - Grazed by cattle
- ✓ 4 replications

Pasture-Crop Rotation Study

Pasture-Crop Rotation Study

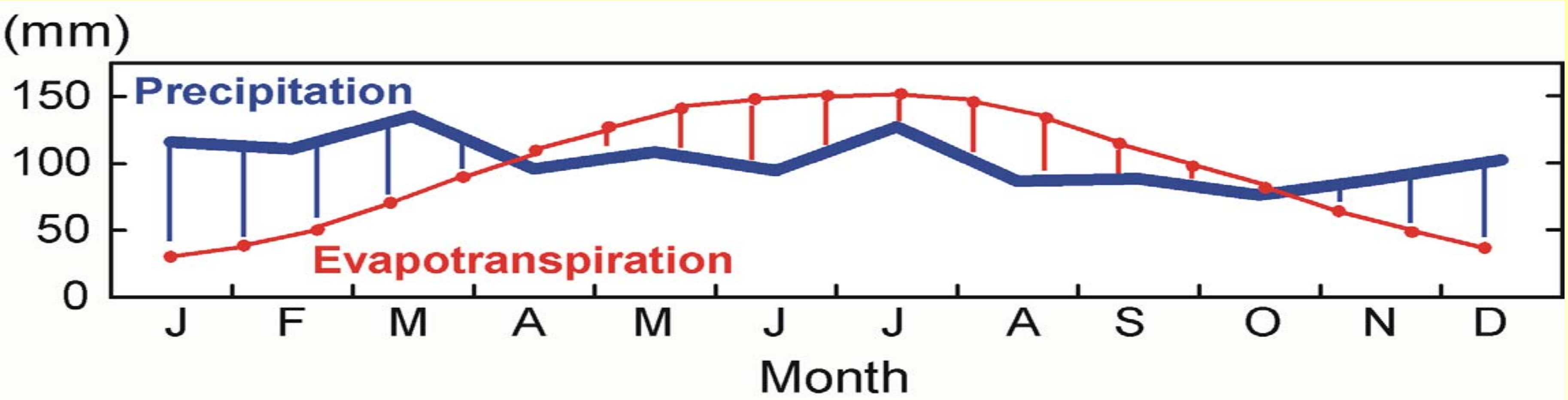
✓ Summer grain – winter cover crop

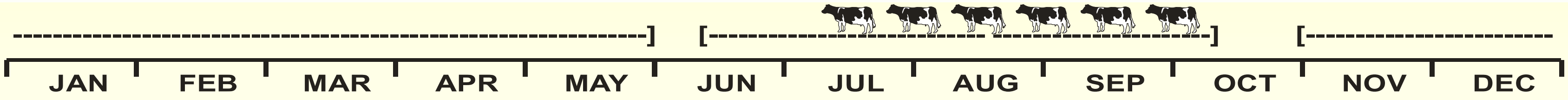




Pasture-Crop Rotation Study

✓ Winter grain – summer cover crop

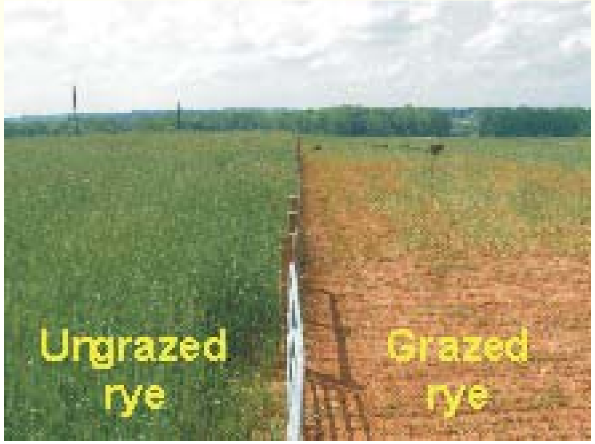




Pasture-Crop Rotation Study

Summer Grain – Winter Cover Crop

	Cover Crop		
Crop component	Unutilized		Grazed
	-------- Mg ha^{-1} --------		
Rye stover	7.4	>>>	0.6
Sorghum grain	2.3		2.2
Sorghum stover	3.7	>	3.0



Pasture-Crop Rotation Study

Summer Grain – Winter Cover Crop

Unpublished data

Crop component	CT		NT
	-------- *Mg ha^{-1}* --------		
Sorghum grain	2.3		2.2
Sorghum stover	2.5	<<	4.2
Rye stover (ungrazed)	7.0	<	7.9

Animal component	CT		NT
Stocking rate *(head ha^{-1})*	6.6	<	9.3
Animal gain *(kg ha^{-1})*	294	<	485
Calf daily gain *(kg head^{-1} d^{-1})*	1.02		1.09

Pasture-Crop Rotation Study

Winter Grain – Summer Cover Crop

	Cover Crop		
Crop component	Unutilized		Grazed
	-------- *Mg ha^{-1}* --------		
Millet stover	10.7	>>>	1.0
Wheat grain	2.1	<<	2.5
Wheat stover	1.1	<	1.3

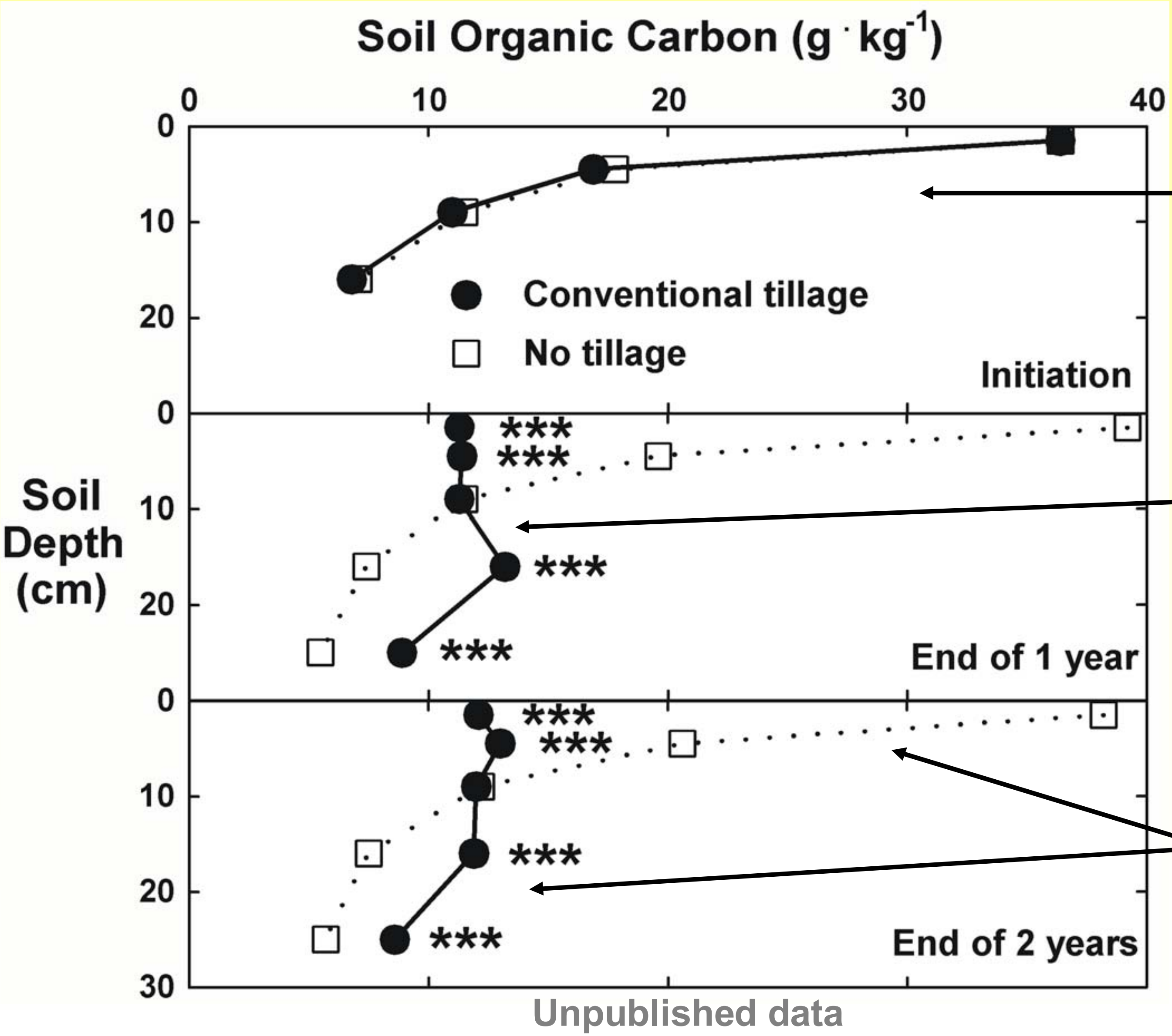
Pasture-Crop Rotation Study
Winter Grain – Summer Cover Crop

Unpublished data

Crop component	CT		NT
	-------- *Mg ha^{-1}* --------		
Wheat grain	2.4		2.2
Wheat stover	1.1	<	1.3
Millet stover (ungrazed)	8.9	<<	12.5

Animal component	CT	NT
Stocking rate *(head ha^{-1})*	7.3	7.0
Animal gain *(kg ha^{-1})*	404	433
Calf daily gain *(kg head^{-1} d^{-1})*	0.93	1.05

Pasture-Crop Rotation Study



Initially high surface C

Following inversion tillage, soil organic C became relatively uniformly distributed with depth

Soil organic C with NT was greater than with CT in the surface 6 cm, but lower than with CT below 12 cm

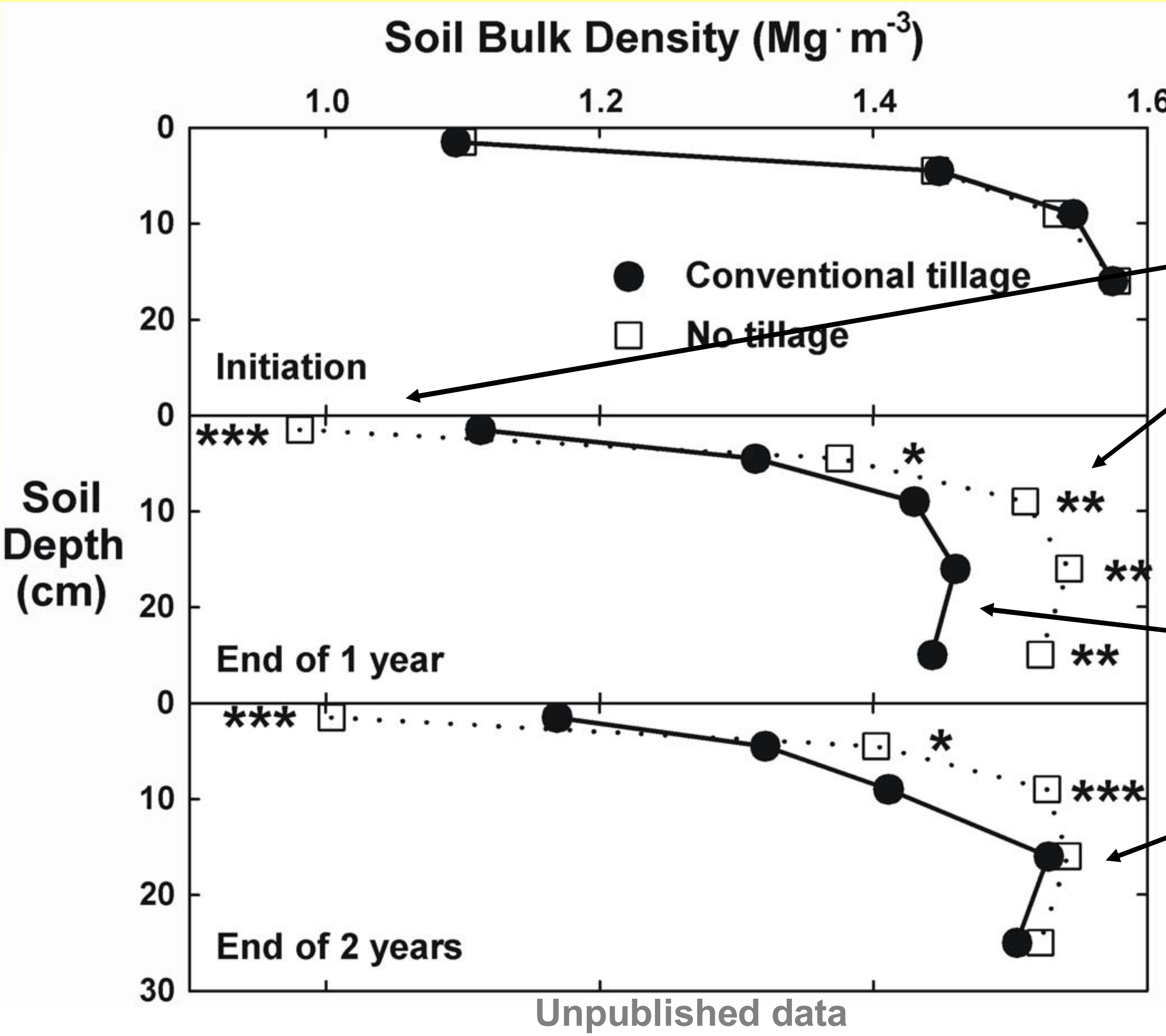
Pasture-Crop Rotation Study

	Soil		Surface Residue	
Time	**CT**	**NT**	**CT**	**NT**
0-20-cm depth	-------------------------	*Mg C ha^{-1}*	-------------------------	
Initiation	37.9	39.2	1.7	1.7
End of 1 yr	33.2 <<	38.9	0.2 <<<	2.2
End of 2 yr	33.9 <<<	40.2	0.5 <<<	4.0

- ✓ Carbon was immediately redistributed within the soil profile with CT, but not greatly mineralized
- ✓ Surface residue C was lost with CT, but accumulated with NT
- ✓ At the end of 2 years, total C stock (soil + residue) under CT was 5.2 Mg C ha^{-1} lower and under NT was 3.3 Mg C ha^{-1} higher than initial C stock (21% difference from initial level of 40.3 Mg ha^{-1})

Unpublished data

Pasture-Crop Rotation Study



Soil under NT remained highly stratified with depth

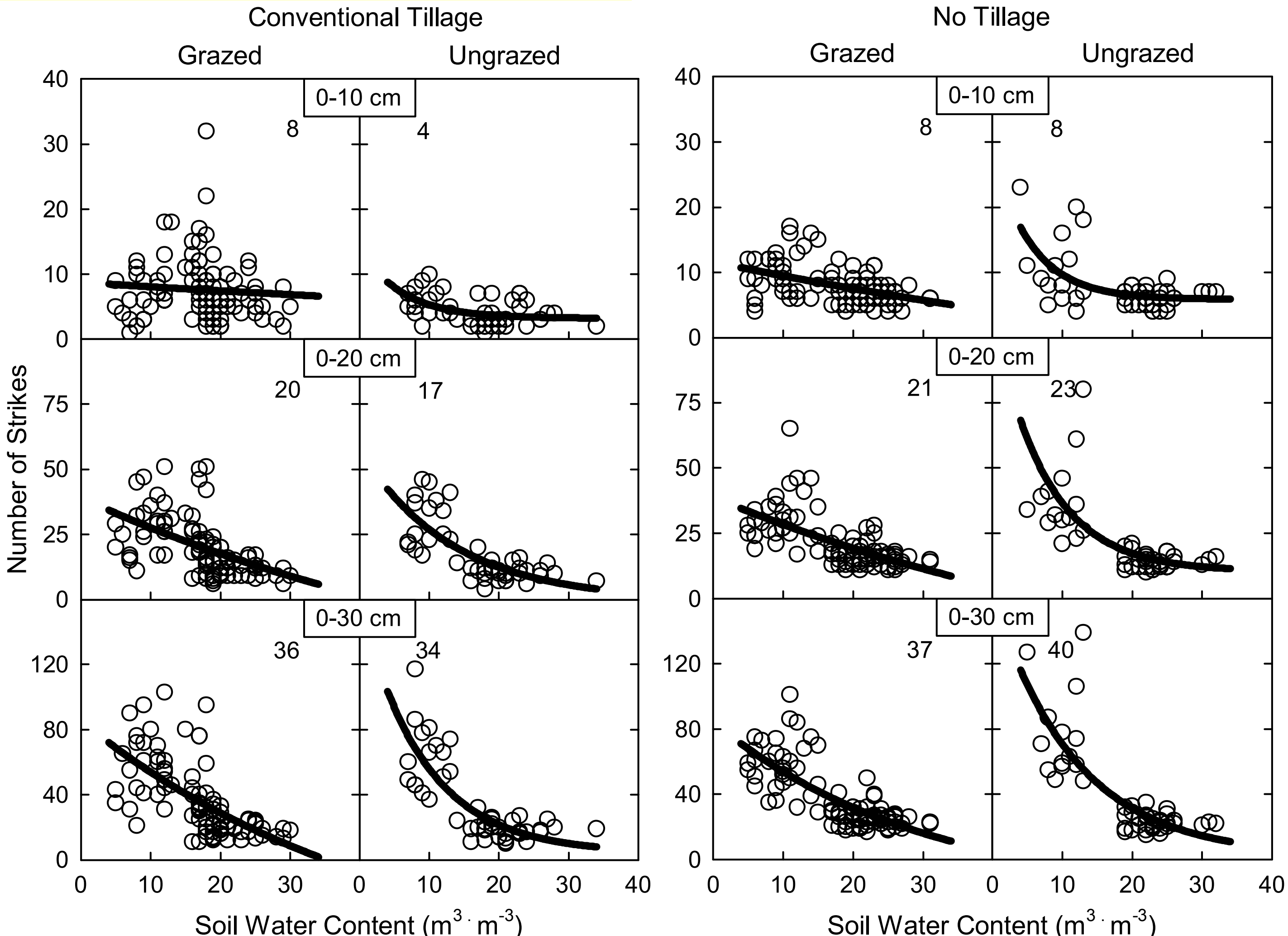
- Low BD at the soil surface
- High BD > 6 cm

Moldboard plowing loosened soil initially following tillage

- However, at 2 years, BD was high >12 cm

Pasture-Crop Rotation Study

Effect of cover crop management under CT and NT on soil penetration resistance



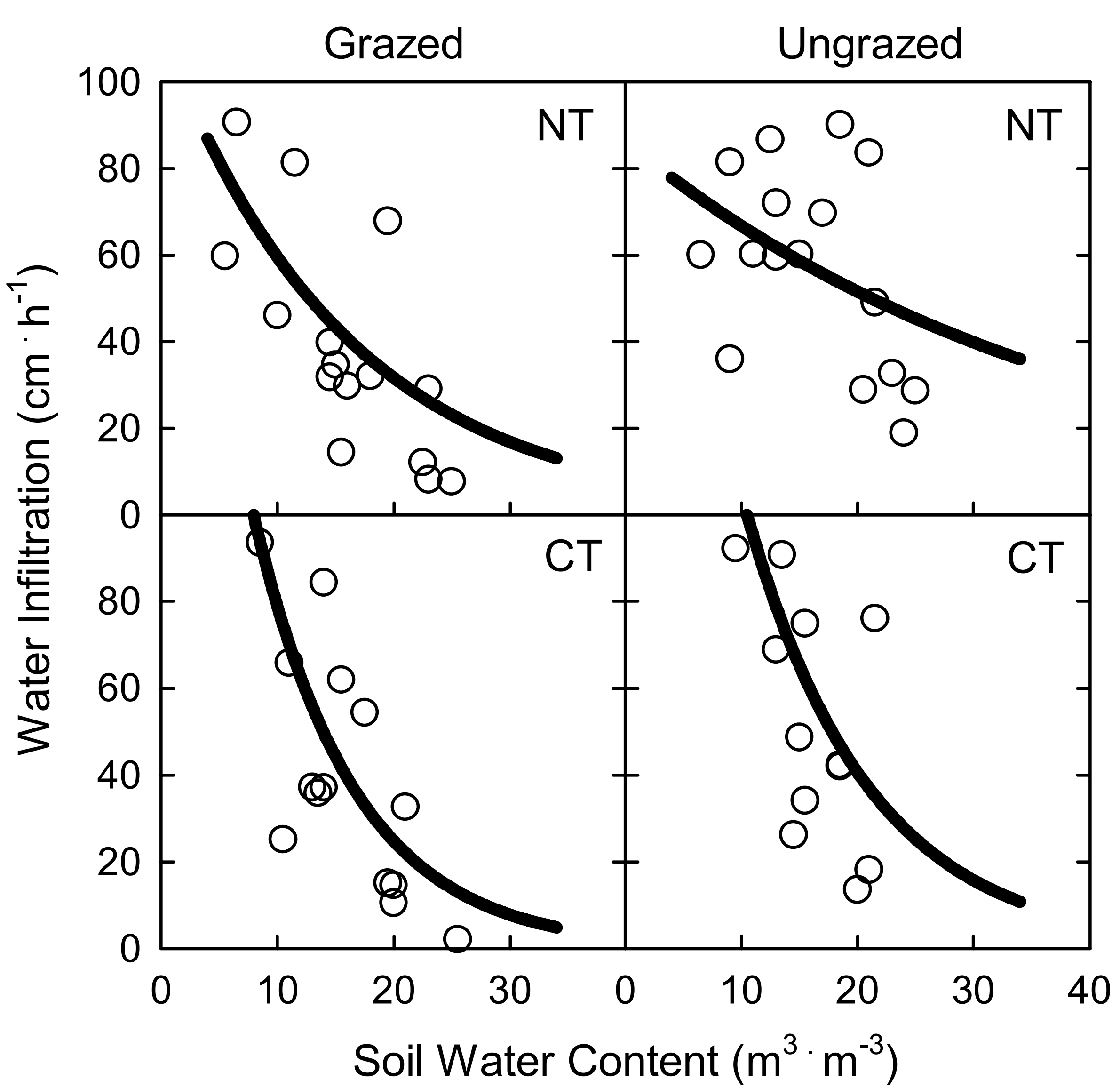
Unpublished data

Soil moisture has big influence on soil penetration resistance.

No major difference in penetration resistance between CT and NT under grazed condition, but lower resistance under CT than NT under ungrazed condition.

Grazing within a tillage system had slight negative effect under CT, but no effect under NT.

Pasture-Crop Rotation Study



Soil moisture had large influence on water infiltration, as expected.

Water infiltration tended to be greater under CT than under NT at low SWC, but lower under CT than under NT at high SWC.

Water infiltration tended to be depressed under cattle grazing of cover crops at SWC >15% under both CT and NT, suggesting that large rainfall events would produce more water runoff when cover crops were grazed than not.

Unpublished data

Summary

- ✓ Establishment of perennial grass pastures can sequester soil organic C at rates of

  0.25 to >1 Mg C ha^{-1} yr^{-1}

- ✓ Soil organic C sequestration rate can be affected by:
  - Forage type (cool- or warm-season)
    (annual or perennial)
    (endophyte-infected tall fescue)
  - Fertilization (inorganic or organic source)
    (rate of application)
  - Forage utilizaton (grazed or hayed)
  - Animal behavior

Conclusions

- ✓ Although some information on SOC sequestration and GHG emission is available, there is a great need to conduct more research on the diversity of pasture systems relevant to agriculture in the eastern USA.

- ✓ Well-coordinated studies across climatic gradients and soil conditions are urgently needed to better understand the effects of major management variables, such as forage type, fertilization, and grazing pressure on ecological and economic responses.

Conclusions

- ✓ **Conservation agricultural systems can preserve soil organic C and help mitigate greenhouse gas emission**
  - **Conservation-tillage cropland**
  - **Pasture management**
  - **Pasture-crop rotation**

- ✓ **Agricultural contribution to net global warming potential requires more extensive research on N_2O emission and CH_4 flux in the southeastern USA**

- ✓ **Low fossil-fuel derived agricultural systems should be developed to further mitigate greenhouse gas emission**